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HYDRAULIC STUDIES FOR LIDDELL POWER STATION

VOL. V: COOLING WATER CIRCULATING PUMP INTAKE

by

K. C. Yong and R. T. Hattersley

May, 1969

THE UNIVERSITY OF NEW SOUTH WALES

WATER RESEARCH LABORATORY

HYDRAULIC STUDIES FOR LIDDELL POWER STATION.

VOL. V: Cooling Water Circulating Pump Intake

by K.C. Yong and R.T. Hattersley

Report No. 110.

Final Report to the Electricity Commission of New South Wales

May, 1969.

Preface

The hydraulic investigations and model studies reported in this volume are part of comprehensive studies carried out by the Water Research Laboratory on behalf of the Electricity Commission of New South Wales.

Throughout the program close collaboration of the engineering staff of the Electricity Commission enabled the studies to be completed in good time to meet the Commission's requirements. The effective co-ordination maintained by Messrs. K.S. Watson and N. Lamb is gratefully acknowledged.

The work involved a number of members of the staff of the Laboratory and the authors gratefully appreciate the advice and assistance given.

R.T. Hattersley,
Assoc. Professor of Civil Engineering,
Officer-in-Charge.

SUMMARY.

The successful tenderers for the main condenser cooling water pumps submitted designs for mixed flow pumps. The pumps are to be fitted with vane control of the water at the suction inlets to cope with changes of water level in the Liddell cooling pond as it is gradually filled.

To meet operating conditions the Electricity Commission requires an arrangement of five pumps one of which is a stand-by arranged in a chamber in juxtaposition to the cylindrical self-cleaning circulating water screens.

Model experiments were conducted to achieve a satisfactory design of pump chamber which included accommodation for the screens. The final design of the screens evolved after a number of trials and the test results are contained herein. These show satisfactory control of pre-entry swirl and velocity distribution in the pump entrances and freedom from air entrainment.

REPORT 110.

HYDRAULIC STUDIES FOR LIDDELL POWER STATION.

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1. Introduction.

Cooling water for the condensers of the four 500 M.W. Turbo-generators and their auxiliaries is to be pumped from an artificial lake created adjacent to the site of the Power Station.

Original proposals submitted by consultants were for pumps of centifugal design to cope with the range in operating head likely to be experienced as the lake was gradually filled by pumping from the Hunter River.

Subsequently tenders were received and accepted for pumps of mixed flow design with provision for the setting of control vanes at the pump inlets to cope with the change in static head.
Vane control of the intake flow of a vertical shaft mixed flow pump is an innovation in design of power plant cooling systems. It was introduced to cope with the wide variations in water level at the supply channel. For satisfactory operation of vane control, the pump intake must be carefully designed to control pre-entrance swirl within small limits. Figure 1 shows the location of the cooling water circulating pump intake in relation to Liddell Power Project.
The datum levels used in this report refer to standard datum.

2. Description of Pumping Plant.

The cooling water pumping system will consist of five 108 inch mixed-flow vertical spindle pumps, each having a pumping capacity of 560 c.f.s. There will normally be four pumps out of five operating at any one time, delivering a total flow of 2240 c.f.s. of cooling water. The pumps, which are arranged in a single row, are symmetrically disposed about the centre line between four cylindrical drum screens. The central pump is to serve as a standby for the other four pumps. This pumping system is referred to as the main cooling water circulating pump intake as distinct from the two pumps used for low pond level (RL. 370) operation.

The four circular drum screens, each 46 feet in diameter, are used to remove debris from the incoming water. After passing through the screens and before reaching the pump pits the water enters a common forebay. The four screen chambers in which the drum screens are accommodated are positioned approximately opposite the four duty pumps. Water enters each screen chamber from inlet chambers on either side of it.

A general layout of the pump intake is given in Figure 2. The water from the cooling water pond by way of an open channel, passes through trash racks and is them deflected vertically upwards and then horizontally before entering the inlet chambers. It then makes a horizontal turn through the openings into the screen chambers, and from the screen chambers it turns horizontally and vertically downward through the screens into the common forebay of the pump pits by way of the screen chamber outlets. The water is withdrawn to the condenser units by four pumps. After passing through the condenser units, the water is finally discharged to the cooling pond by way of a series of conduits and open channels, to complete the loop for the circulation of cooling water.

When the power station is first programmed for operation, the pond may not have reached the normal minimum operating level of RL. 405'. Two pumps are therefore designed to operate with pond levels as low as RL. 370'. These pumps will subsequently be modified to operate with pond levels at and above RL. 405'. By progressive filling of the pond from the Hunter River during the first two years of operation, the pond will rise above RL. 405' and is to be maintained at or above this level at all subsequent times. The operating level at the pump suctions will normally vary between RL. 405' and RL. 425' but under extreme flood conditions the pond surface can rise to a maximum level of RL. 433' (Ref. 1).

3. Statement of Problem.

Model studies were made only for the main cooling water circulating pumps designed to operate with water levels above RL. 405 as shown in Figure 2. Since the low level pumps for operation at RL. 370 will be used only for a short time, model studies to refine their intake were not considered warranted.

The hydraulic model design of the pump intake includes the following:

(i) The most suitable method of getting water from all or any combination of the four screens to any combination of four or fewer out of the five pumps;

(ii) The hydraulic design of the following items:
   (a) the inlet chamber entrances
   (b) the inlet chambers
   (c) the screen chambers
   (d) the screen chamber outlets

(e) the common forebay
(f) the approach channels
(g) the pump pits.

The objective is to achieve a design of the pump intake in which the pumps operate free from vibration and air-entrainment and also to ensure that design performance is not vitiated by adverse flow conditions occurring in the intake channels.

4. The Model.

4.1 General.

The scale was chosen after consideration of the space and facilities available at the water Research Laboratory to operate the model. For experiments of this kind it is desirable to keep the geometric scale in the range 1:24 to 1:5 this being the range in which approximate compatibility is feasible between wall effects and surface-gravitational effects in the free surface channels (See Ref. 3).

The experimental investigations were carried out in a 1 to 16 scale model of the pump intake. The velocity and discharge scales were determined by assuming firstly model and full scale Froude Numbers equal. The presence of surface vortices detectable in a model is indicative of the presence of more clearly defined prototype vortices. A submerged vortex at a pump intake is a result of vorticity in the approach flow while air entrainment is a result of the presence of air-entraining vortices. Hence the vortex in the suction pipe can be used as a swirl detector as well as indicator of the likelihood of air-entrainment.

For Froude similarity, the pertinent ratios between prototype and model are as follows:-

Linear scale (L_r) $= 16$

Velocity scale (V_r) $= L_r^{\frac{1}{2}} = 4$

Discharge scale (Q_r) $= L_r^{5/2} = 1024$

Time Scale (T_r) $= L_r^{\frac{1}{2}} = 4$

The structures modelled consisted of the inlet chambers, the screen chambers, the common forebay and the pump pits. The intake model was accommodated in an open top tank 11ft by 12ft. high. The tank was bounded on three sides by plywood walls and one side by a 3/4" thick "Perspex" wall. The pumps were located near the Perspex wall so that observations could be made through the Perspex, (See Figures 3a and 3b). The general layout of the model intake with the arrangement of pipe work and pumps for circulating the water is shown in Figure 4.

4.2 Operation of the Model.

Five Perspex suction inlets were used to represent the suctions of the pumps. Provision was made to seal off any one of the five suction pipes as desired to enable tests to be carried out for any combination of four pumps operating. The five suction pipes were connected to a 8 inch diameter pipe manifold which was in turn connected to two 6-inch centrifugal pumps. The water was withdrawn from the tank by the pumps through the suction inlets, the total flow rate being measured by an orifice meter located in the pipe line that carried the flows from the two 6-inch pumps back to the head box. A butterfly valve was installed in each suction pipe for regulating the flow into the suction inlet. Pitot tubes installed upstream of the butterfly valves were connected to a balance manifold by plastic tubes. The butterfly valves were adjusted until equal pressures were registered on the manometer tubes indicating the same flow through all the suction inlets. For further details, see Figures 3a, 3b and 4.

The water level in the tank could be adjusted to any required level by either adding water through a 3-inch diameter supply pipe or letting water out through a dump valve. The normal operating level for tests varied from RL. 405' to RL. 422.5'.

4.3 Model Suction Inlet.

The throat diameter and the bellmouth outside diameter were assumed from past experience, as this information was not available from the pump manufacturers at the time of design and construction of the model. A 6-inch O.D. (5¼" I.D.) perspex tube was used to represent the suction throat and the bellmouth was moulded to 9 inches O.D. These represent prototype throat diameter of 7 feet 8 inches and bellmouth diameter of 12 feet. The accepted tender for the pumping plant indicated the bellmouth outside diameter as 15 feet, giving an effective bellmouth diameter of 12 feet, which was comparable to the bellmouth diameter used in the model tests.

4.4 Simple Model Bellmouth.

Simple model bellmouths as given in Figure 5 were used in the test programme for the design of such structures as the screen chamber outlets, for their position relative to the pump centre lines, for the common forebay, the approach channels, the dividing piers and their nosings, and the splitters and their nosings. The bellmouth was subsequently moulded to the shape finally adopted and a structure with five meridional vanes added underneath the bellmouth (see Section 5.6 for details). The basis of the vane disposition was submitted by tenderers for the pumping plant.

4.5 Instrumentation of the Model Suction Inlet.

4.51 Vortometer.

Swirl in the suction pipe was measured by a series of four freely pivoted meridional vanes known as a vortometer, mounted vertically and co-axial with the model suction pipe. The vanes were used to detect tangential components in the flow into the suction inlet. For details of the vortometer and the techniques of measurement refer Reference 3.

The vortometer was used as an aid in the formulation of a satisfactory design of the pump intake. Figure 6 shows the vortometer mounted on a model suction pipe.

4.52 Directional Pitot-Static Tube for velocity measurement.

A special type of pitot-static tube was made and fitted into the suction pipe immediately above the vortometer for measuring the velocity distribution across the entire throat diameter. This served as a check on the uniformity of flow into the bellmouth. This device is shown in Figure 6. The special features and the operation of this directional pitot-static tube are given in Appendix A.

4.53 Pressure tappings around the periphery of the bellmouth.

Ten pressure tappings at equal intervals were made around the periphery of the model bellmouth. The tappings were all connected to a balance manifold from which the relative pressures at the tappings could be observed. The pump pit and the bellmouth were proportioned to enable balanced flow into the suction inlet with uniformity of flow around the lip of the bellmouth. The uniformity of flow was indicated by equal pressures in the tappings. The general arrangement of the pressure tappings is shown in Figure 6.

5. Test results and discussion.

5.1 General.

From the model experiments, an acceptable design of the pump intake was evolved with the general arrangement as shown in Figure 2. The details of the design and related discussions will be given with reference to Figure 2 in the following sections.

5.2 The Inlet Chambers.

Following an hydraulic investigation in a 1:32 scale model of the inlet and screen chambers as reported in Reference 4 the following features were incorporated in the 1:16 scale model:-

(i) Installation of a sloping ramp in the inlet chambers to improve flow into the screen chambers.

(ii) Increasing the height of the inlet chamber openings to RL. 419' and rounding of edges at approach to improve entry conditions and reduce headloss through the inlet chambers and the screen chambers to a minimum.

5.3 The Screen Chambers.

Prior to the construction of the model the head loss was estimated for the 46 feet diameter drum screen with width varying from 11 feet to 16 feet under different flow conditions to appraise the effects of various screen sizes (Reference 4). Subsequent to this study, a 9 feet wide screen was accepted with an overall width of 12'3", which was incorporated in the model. The head loss characteristics of the screen material were obtained from hydraulic tests reported in Reference 4 and are shown in Figure 7

The centre lines of the two extreme screen chambers (1 and 4) were located 2'3" offset from the centre lines of the two extreme pumps (2 and 4), whereas the centre lines of the other two screen chambers (2 and 3) were in line with the centre lines of the pumps 1 and 3. This arrangement gave a more or less direct approach from the screen chamber outlets to the pump pits under normal operating conditions.

5.4 The Screen Chamber Outlets.

The size of each screen chamber outlet was 16' by 12'3". The positions of these screen chamber outlets were adjusted by lengthy trials in a series of model experiments. Results of the observations indicated that the most satisfactory solution was obtained when the outlets were positioned with their centre lines in line with the centre lines of the screen chambers.

The hydraulic tests carried out for the design of the approach channels and pump pits were based on these dimensions for the screen chamber outlets. Subsequently the height of the screen chamber outlets was raised to 18 feet, but this was not incorporated in the model for testing, as the change in height of the outlets was not sufficient to cause significant change in the entrance conditions to the pump chambers.

5.5 The Pump Chamber.

5.51 General.

To meet the design conditions described in Section 3, the pump chamber and adjoining forebay were proportioned arbitrarily based on experience of previous tests (Ref. 2 and 3) and developed finally by progressive adjustment on the model. The pump chamber was designed with a nominal approach length of three bellmouth diameters, that is 36 feet. This distance was judged from experience on past model tests as sufficient to control the flow pattern in approach to the pump suctions.

Sixteen (16) feet was allowed as the minimum width of the common forebay. This figure corresponded approximately to optimum water velocities at a water level of RL. 405'.

It should be noted here that for the investigations for the hydraulic design of the items described in the following sections, the vertical axes of the pumps were arranged on the centre lines of the approach channels. Simple bellmouths were used. The bellmouth was set at half the bellmouth diameter (D) from the floor. The back wall around the pump casing was shaped in accordance with the requirements of an ideal arrangement for a simple bellmouth (Ref. 2) i.e. 0.65D from the centres of the pumps to the back wall. The widths of the approach channels at the centres of the pumps were fixed at 1.4D.

5.52 The Common Forebay.

Tests were conducted in the model covering the range of operations at RL. 405' for four screens and any combination of four out of five pumps. The common forebay had to be designed to cope with cross flow of varying severity depending on the combination of pumps operating. It was observed that, for a 16 feet transverse passage, the flow at the nosings of the dividing piers adjacent to the middle pump unit (No. 5) suffered from severe interference. Further model experiments revealed that it was necessary to set the said dividing piers back 7 feet relative to the two extreme dividing piers.

The semi-circular nosing at the leading edge of each pier was essential to provide a smooth transition for flow from the common forebay into the approach channels. The semi circular nosings reduce the region of separated boundary layer flow to an acceptable extent, without excessive vortex shedding.

With the inside dividing piers set back, satisfactory flow conditions prevailed in the common forebay. The transitional flow around the nosings of the piers and into the approach channels was also observed to be satisfactory.

Further tests showed that the intake continued to operate satisfactorily at operating levels above RL. 405'. Above RL. 420', the dividing piers were no longer necessary.

Following the inspection of the model operation by Electricity Commission and subsequent discussion, it was agreed that the height of the nosings of dividing piers did not need to rise above RL. 420'.

5.53 The Approach Channels.

For this pump intake, the layout dictated differently shaped approach channels from pump to pump. A splitter was used to divide the approach flow into two streams. The splitter served to control the distribution of vorticity in the flow converging towards the pumps.

The shape and the position of the splitters were adjusted by model experiments at RL. 405' until the swirl registered by the vortometer in the suction pipe was a minimum attainable. The convergent passages were designed to give a mean velocity of flow not more than 3 to 4 f.p.s. as a precaution against air-entrainment through the activity of surface disturbances. Moreover, it was found necessary to maintain the mean velocity in that range so that it would be greater than the magnitude of the local velocity fluctuations and so provide flow stabilization in the channels.

To determine the height of the splitters, tests were carried out at different operating levels and the effect on the performance of the pumps observed. It was found that the splitters could be terminated at RL. 405', but, at high operating levels, it was necessary to provide vertical diaphragm walls across the entrances to the channels, from RL. 405' to RL. 420' to prevent the swirling water in the common forebay from affecting the performance of the pumps. This condition applied only when the simple bellmouths were used in the tests.

Subsequent to the installation of the "spiders" (Structures with five meridional vanes) under the bellmouths, it was found from further tests at different operating levels that only the middle pump unit (no. 5) needed a diaphragm wall to steady the inflow from the middle pump pit and to allay cross interference with the flow into pump units No. 1 and No. 3, when pumps 1, 2, 3 and 4 are operating.

During the operation of the pump intake, there will be occasions when any one of the pumps will need to be isolated for inspection and maintenance. So that individual pump pits may be dewatered, stop logs will be used spanning across the entrances to the approach channels. To facilitate the lowering of the stop logs, the diaphragm wall may be used as a guide wall. Although, as was pointed out earlier, a diaphragm wall was hydraulically required only for the pump unit No. 5, diaphragm walls could also be installed for the other pumps to serve as guide walls for lowering the stop logs. Hydraulically, the diaphragm walls had additional minor steadying effects for pumps operating at high water levels.

5.54 The Pump Pits

An individual pump pit is defined as the region in the immediate vicinity of the pump casing.

During the construction of the pump intake model, thin sheets of flexible transparent "celluloid" were used to form the boundaries of the pump pits for the following reasons:-

(i) To enable visual observations of the performance of the pumps to be made through the Perspex window, and

(ii) To enable adjustments to be made to the shape of the back wall of the pump pit.

In the initial shaping of the boundaries of the pump pits, the rear walls of the pump pits were set at 0.65 times the diameter (D) of the bellmouth from the centres of the pumps, while the width of the approach channels at the centres of the pumps was fixed at 1.4D.

Model trials were arranged to test for the presence of surface vortices under different operating conditions and it was found that air-entraining vortices occurred at practically all the pumps for water surface levels below RL. 410'. Since the pumps were all in "terminal" positions (as defined in Ref. 2) a form of wall roughening (Fig. 2 and 10) was devised to interfere with the vortices that tended to appear at the backs of the pump casings. A horizontal perforated baffle plate (Figure 2) hanging at RL. 404', i.e. with one foot of water cover at minimum operating level, was also found to be effective in interfering with the vortices. For details of the wall roughening and the horizontal baffle plate, refer to Section 5.7.

Pre-entry swirl as measured by the vortometers was also present, of varying magnitude and unsteadiness, but well within tolerable limits. The pre-entry swirl was further reduced to the minimum attainable and unsteadiness was practically eliminated when the final bellmouths with spiders were installed for testing (see Section 5.6 for details).

5.6 Design of the bellmouth, and its associated structure underneath the pump bell.

5.61 General

The bellmouth and its associated structure as proposed by the pump manufacturer were incorporated in the model for final check. The bellmouth had an outside diameter of 15 feet but the effective diameter could be taken as 12 feet, which was comparable to the diameter of the simple bellmouth used previously. Underneath the bellmouth there were five meridional vanes equally spaced. These vanes were designed in the form of streamlined piers to train the flow into the pump inlet. The details of the bellmouth and its associated structure are given in Figure 8.

To test the effectiveness of this bellmouth and its associated structure, ten pressure tappings were installed around the periphery of the bellmouth. These tappings were connected to a balance manifold from which the relative pressures could be observed as a check on the uniformity of flow around the lip of the bellmouth.

Model experiments indicated that the edge of the bellmouth should be rounded for smooth transition of flow. Also a 2'6" high fillet was required in the space between the rear wall and the bellmouth to prevent stagnant water from interfering with the turning flow into the pumps (see Figure 8 for details). To achieve near uniform flow around the lip of the bellmouth, it was found necessary to increase the radius to the rear wall to 8'6". With this arrangement, the shape of the rear wall took the form of a semi-circle with radius of 8'6". Subsequent tests indicated that it would be desirable to reduce the outside diameter of the bellmouth from 15'0" to 14'6" to further improve the flow conditions into the pump inlets and at the same time to provide a shape of simple curvature for ease of construction.

To further check the uniformity of flow into the suction pipes, a directional pitot static tube (see Section 4.52 for details) was installed across the diameter of the suction pipe at the likely position of the pump impeller. The measured velocity distribution across the suction pipe, shown in Figure 9, indicates that uniform flow into the pump suction prevailed.

Check tests were carried out with all the spiders in position under the bellmouths for any combination of four of the pumps with four screen chambers operating for water surface levels from RL. 405' to RL. 422.5'. Visual observations indicated that the pumps were operating very satisfactorily except that there were small air-entraining vortices occurring at the backs of the pump casings for water surface levels below RL. 410'. These vortices could be prevented by either roughening the rear wall of the pit or by installing a horizontal perforated baffle plate 1 ft. below minimum operating level. The details of the two methods will be given in Section 5.7.

5.62 Height of Bellmouth above Floor.

For the simple bellmouth, the height of bellmouth above the channel bottom for achieving the maximum steadiness was fixed from previous experience (Ref. 2) at half the bellmouth diameter (D). When the final bellmouth was installed for checking, it was found that the pumps were operating satisfactorily for bellmouth clearance of 1/3D i.e. 4ft. from the floor to the lip of the bellmouth.

5.63 Depth of Submergence of Lip of Bellmouth.

The initial floor level was fixed at RL. 389' but subsequently it was increased to RL. 390'. Instead of altering the floor level in the model, it was decided to lower the operating levels by 1 ft. to accomodate the effect. For the minimum water surface level at RL. 405' and the floor level at RL. 390', the depth of submergence of the lip of bellmouth was measured to be 11ft. for the final bellmouth. Experiment showed that one foot difference in depth of submergence did not affect the performance of the suction inlet.

It has been shown (Ref. 5) that except in the rare circumstances where resonance occurred, the waves in the pump chamber resulting from the conditions in the cooling pond, will be less than 1 foot with a period range up to 3½ seconds. The transient reduction in submergence due to these waves will not be a problem.

During model operation a drawdown of 3 ft. took place on initial starting of pumping. With such a starting surge on a prototype design using a horizontal baffle, some air would be carried into the pump by air-entraining vortices until the water level was resotred to above the horizontal baffle plate at RL. 404.

5.7 Design of the Roughened Walls and the Horizontal Perforated Baffle Plates

As mentioned in previous sections (for example, 5.54), after the installation of the final bellmouths with spiders, there was still evidence of small vortices appearing at the back of the pump casings for water surface levels below RL. 410'. Control of the growth of air entraining vortices at the rear of the pits was effected by either of the following methods:-

(i) By artificially roughening the rear wall of the pits to produce turbulence of sufficient energy to destroy vortex formation. This was done by providing a band of 6" cubes spaced at 24" centre to centre staggered. The extent of the roughened wall for each pit was a circular arc of length approximately 14'6" on plan and in elevation it extended from RL. 398'6" to RL. 409' (see detail B of Figure 10).

(ii) By hanging a horizontal baffle plate in the shape of a circular arc with 4" diameter openings at 9" centre to centre around the rear wall of each pit at RL. 404". The extent of this installation is shown in detail A of Figure 10.

Both methods were found to be effective in controlling the growth of air entraining vortices. In addition, the roughened wall had some steadying effect on the performance of the pump. The final selection of either of the above methods would depend on the relative costs of construction: hydraulically, both methods were effective. It should be noted that the protective measures were only needed for operating levels below RL. 410'.

5.8 Check Tests on the Performance of the Final Design of the Pump Intake.

A final check test on the design of the pump intake that had evolved from the above model experiments was made with all the spiders in position under the pumps for any combination of four pumps with four screen chambers operating. The operating levels varied from RL. 405' to RL. 422.5'. Included in the final test series were also the following operating conditions:-

(i) Two pumps (1 and 2) opposite two screen chambers operating for Q = 1120 c.f.s.

(ii) Two pumps (1 and 2) with two far end screen chambers (3 and 4) operating for Q = 1120 c.f.s., and

(iii) Four pumps (1, 2, 3 and 4) with three screen chambers (1, 2 and 3) operating for Q = 2240 c.f.s.

This range of tests gives a reasonable coverage of normal and critical operating conditions.

Measurements were made for four water surface levels, namely RL. 405', RL. 410', RL. 415' and RL. 420' for the above listed operating conditions. No tests were carried out for water surface level at RL. 422.5', for it was considered that if the pump intake behaved well at RL. 420', it would perform well for water surface levels above RL. 420'. In each case the vertical velocity distributions at various locations were measured with an Ott current meter and the flow patterns traced with dye. No velocity maldistribution likely to affect pump operation was found. At high operating levels the surface flows in the pump forebay and on approach to pump bells were observed to be characterised by circulation. Detailed results are given in Appendix B. The operational information as obtained from the model tests could be useful for the operating and the maintenance of the pump intake.

In addition, the headlosses through the inlet and the screen chambers were measured for RL. 405' and RL. 420' as a check against the results obtained from a 1:32 scale model of the screen chamber and the inlet chambers. The results are given in Table 1.

The performance of the pump intake was obtained by observing the pre-entry swirl as indicated by the vortometers and the evidence of any air-entraining vortices. The pre-entry swirls as measured by the vortometers for pumps under various operating conditions are recorded in Table 2. As can be seen from the results given in Table 2 the pre-entry swirls recorded can be considered negligible. No air-entraining vortices were observed over the range of tests carried out.

6. Conclusion.

The experimentally derived design of the main cooling water circulating pump intake was shown to perform satisfactorily in the model. The model is expected to give reliable indications of full scale behaviour, both in regard to swirl correction and freedom from air-entrainment.

7. References.

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(3) Hattersley R.T. "Factors of inlet channel flow affecting the performance of pumping plant. "Report No. 23, Water Research Laboratory, University of New South Wales, Australia, September 1960.

(4) Yong K.C., Nelson R.C., Stone D.M., and Foster D.N. "Hydraulic Studies for Liddell Power Station. Vol. VII: Miscellaneous". Report No. 110, Water Research Laboratory, University of New South Wales, Australia (In Press).

(5) Nelson R.C. and Stone D.M. "Hydraulic Studies for Liddell Power Station. Vol. VII: Miscellaneous". Report No. 110, Water Research Laboratory, University of New South Wales, Australia. (In press).

Table 1: Head Losses for the Screen and the Inlet Chambers

Discharge c.f.s.	Pump combination	Screen Chambers combination	Operating level	Head-losses (ft.)	Remarks
1120	1 and 2	1 and 2	RL. 405′ RL. 420′	0.32 0.20	Same as for pumps 3 and 4 with screen chambers 3 and 4.
1120	1 and 2	3 and 4	RL. 405′ RL. 420′	0.64 0.21	Same as for pumps 3 and 4 with screen chambers 1 and 2.
2240	1, 2, 3 and 4	1, 2 and 3	RL. 405′ RL. 420′	0.64 0.48	Same as for pumps 1, 2, 3 and 4 with screen chambers 2, 3 and 4.
2240	1, 2, 3 and 4	1, 2, 3 and 4	RL. 405′ RL. 420′	0.36 0.24	
2240	1, 2, 3 and 5	1, 2, 3 and 4	RL. 405′ RL. 420′	0.32 0.21	Same as for pumps 1, 3, 4 and 5 with screen chambers 1, 2,3 and 4.
2240	1, 2, 4 and 5	1, 2, 3 and 4	RL. 405′ RL. 420′	0.48 0.24	Same as for pumps 2, 3, 4 and 5 with screen chambers 1, 2, 3 and 4.

Note: The headlosses as measured from a 1:32 scale model of the screen chamber and inlet chambers, for RL. 405' and RL. 422.5' are 0.75' and 0.5" respectively (Reference 4).

Table 2. Pre entry swirls as measured by vortometer for pumps under various operating conditions.

Discharge c.f.s.	R.L. (ft.)	Vortometer reading (Revolutions per second) and rotational direction										Screen Chamber Combinations
		Pump 1.		Pump 2.		Pump 3.		Pump 4.		Pump 5.		
2240	405	0.2	↻	0.16	↻	0.08	↺	0	-	-	-	1, 2, 3 and 4
	410	0.03	↺	0.14	↻	0.11	↻	0.06	↻	-	-	"
	415	0.05	↻	0.02	↻	0	-	0.08	↺	-	-	"
	420	0.04	↻	0.11	↻	0.05	↻	0.10	↺	-	-	"
2240	405	0.07	↻	0.07	↻	0.12	↻	-	-	0.12	↺	1, 2, 3 and 4
	410	0	-	0.12	↻	0.1	↻	-	-	0	-	"
	415	0.03	↺	0.2	↺	0.02	↻	-	-	0	-	"
	420	0.05	↺	0.08	↺	0	-	-	-	0	-	"
2240	405	0.08	↻	0.20	↻	-	-	0	-	0.09	↺	1, 2, 3 and 4
	410	0.05	↺	0.11	↻	-	-	0.04	↺	0.04	↺	"
	415	0.09	↻	0.04	↻	-	-	0.07	↺	0.16	↺	"
	420	0.1	↻	0.04	↻	-	-	0.12	↺	0.12	↺	"
2240	405	0.25	↺	0.2	↺	0.27	↻	0.24	↺	-	-	1, 2 and 3
	410	0.3	↺	0.07	↺	0.28	↻	0.28	↻	-	-	"
	415	0.11	↺	0.09	↺	0.11	↺	0.07	↻	-	-	"
	420	0.1	↺	0.11	↺	0.14	↺	0.11	↻	-	-	"
1120	405	0.03	↺	0	-	-	-	-	-	-	-	1 and 2
	410	0.06	↺	0.1	↻	-	-	-	-	-	-	"
	415	0.02	↻	0.09	↻	-	-	-	-	-	-	"
	420	0.09	↻	0	-	-	-	-	-	-	-	"
1120	405	0.11	↺	0.11	↺	-	-	-	-	-	-	3 and 4
	410	0.14	↺	0.2	↺	-	-	-	-	-	-	"
	415	0.21	↺	0.1	↻	-	-	-	-	-	-	"
	420	0.20	↺	0.08	↻	-	-	-	-	-	-	"

Appendix "A".

Details of a Directional Pitot-Static Tube for Velocity Measurement

Description.

The directional pitot-static tube is in fact a modified version of the direction-finding tube. A direction-finding tube is a cylindrical tube having two piezometer holes located $78\frac{1}{2}^{\circ}$ apart as shown on Detail G of Figure 6. Each piezometer is connected to its own measuring device. The tube may be rotated until both piezometers show the same reading. Then from symmetry the direction of flow can be determined. This device not only determines the direction of flow but also the static pressure.

The directional pitot-static tube is a direction-finding tube with an extra piezometer hole drilled through the outer tube into an inner tube of smaller diameter for measuring the stagnation pressure. This piezometer hole is located half way between the other two holes, but slightly offset from a transverse line connecting the centres of the two piezometer holes on the outer tube. The piezometer hole on the inner tube is connected to its own measuring device whereas the other two piezometer holes on the outer tube are connected to a common measuring device. The details of the directional pitot-static tube are shown in Figure 6.

The directional pitot-static tube was made to slide on a guide rod so that the piezometer holes can be moved from the centre of the suction pipe to its wall. A scale was scribed on the surface of the outer tube to provide accurate location of the position of the piezometer holes.

Method of Measurement.

The combination of a direction-finding tube for static pressure measurement and a pitot-tube for stagnation pressure measurement into a single device is to enable the measurement of velocity head as well as the direction of flow at the same time. The procedure is to orient it so that the piezometers give the maximum difference in the two readings which indicates the velocity head as well as the direction of flow.

Appendix "B".

Summary of Results of Velocity Distributions and Flow Patterns.

The vertical velocity distribution and the flow patterns in the intake were measured from a series of model tests under different operating conditions. The information could be useful for the operation and the maintenance of the pump intake and was recorded for the following operating conditions:-

I. (1) Pumps 1, 2, 3 and 4.
(2) Screens 1, 2, 3 and 4.
(3) Q = 2240 c.f.s.
(4) Operating levels from RL. 405' to RL. 420'.

II. (1) Pumps 1, 2, 3 and 5 or 1, 3, 4 and 5.
(2) Screens 1, 2, 3 and 4.
(3) Q = 2240 c.f.s.
(4) Operating levels from RL. 405' to RL. 420'.

III (1) Pumps 1, 2, 4 and 5 or 2, 3, 4 and 5.
(2) Screens 1, 2, 3 and 4.
(3) Q = 2240 c.f.s.
(4) Operating levels from RL. 405' to RL. 420'.

IV. (1) Pumps 1, 2, 3 and 4.
(2) Screens 1, 2 and 3 or 2, 3 and 4.
(3) Operating levels from RL. 405' to RL. 420'.
(4) Q = 2240 c.f.s.

V. (1) Pumps 1 and 2.
(2) Screens 1 and 2.
(3) Q = 1120 c.f.s.
(4) Operating levels from RL. 405' to RL. 420'.

VI. (1) Pumps 1 and 2.
(2) Screens 3 and 4.
(3) Q = 1120 c.f.s.
(4) Operating levels from RL. 405' to RL. 420'.

The results for items I, IV and VI for operating levels at RL. 405' and RL. 420' are given in Figures 11 to 20.

The rest of the results are contained in a series of original drawings (Figs. 21 to 41) which are held at the W.R.L. These figures do not appear in this report as reproduction in quantity is not warranted. The drawings are available for future reference and comparison with prototype behaviour.

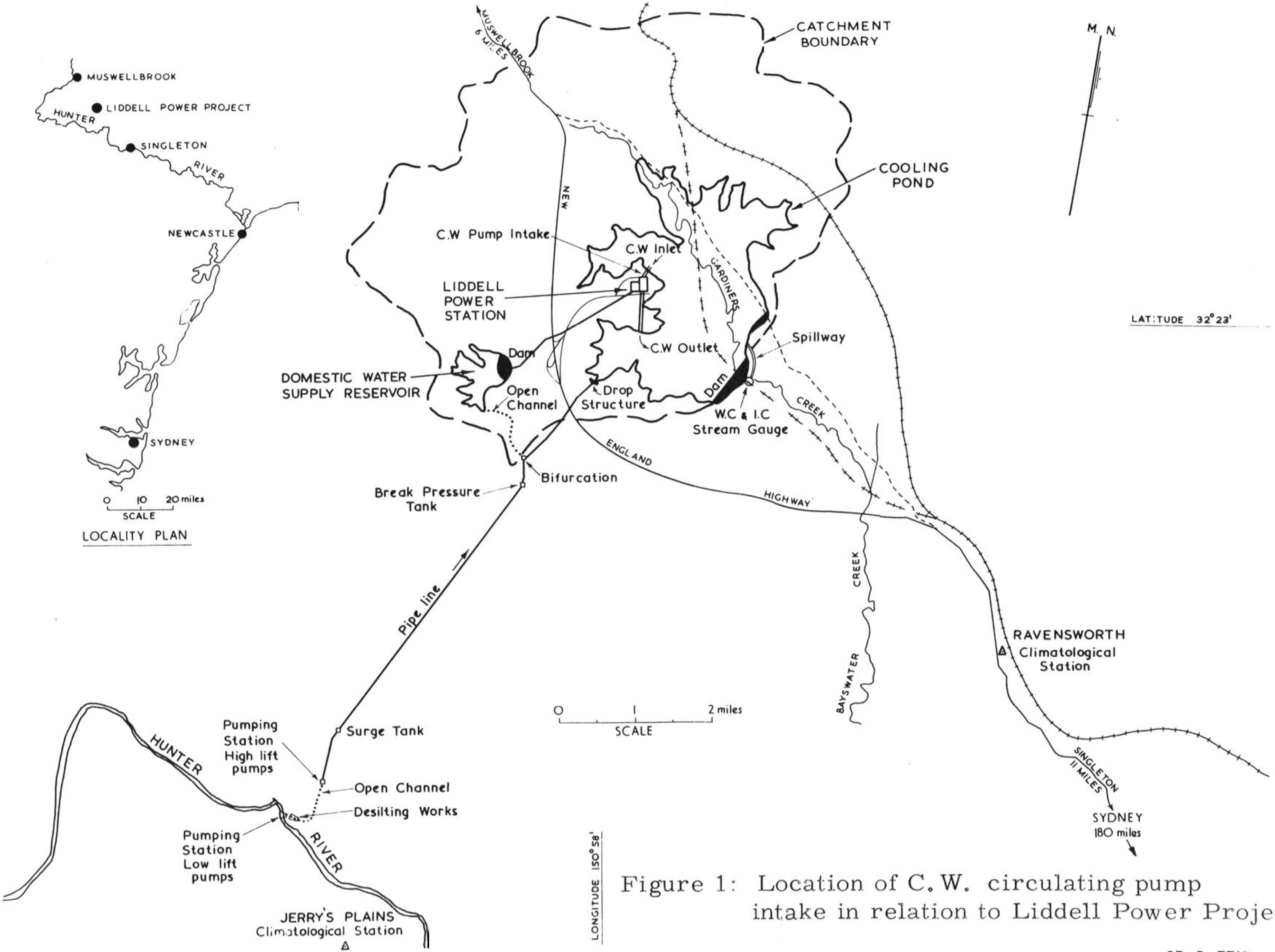

Figure 1: Location of C. W. circulating pump intake in relation to Liddell Power Project.

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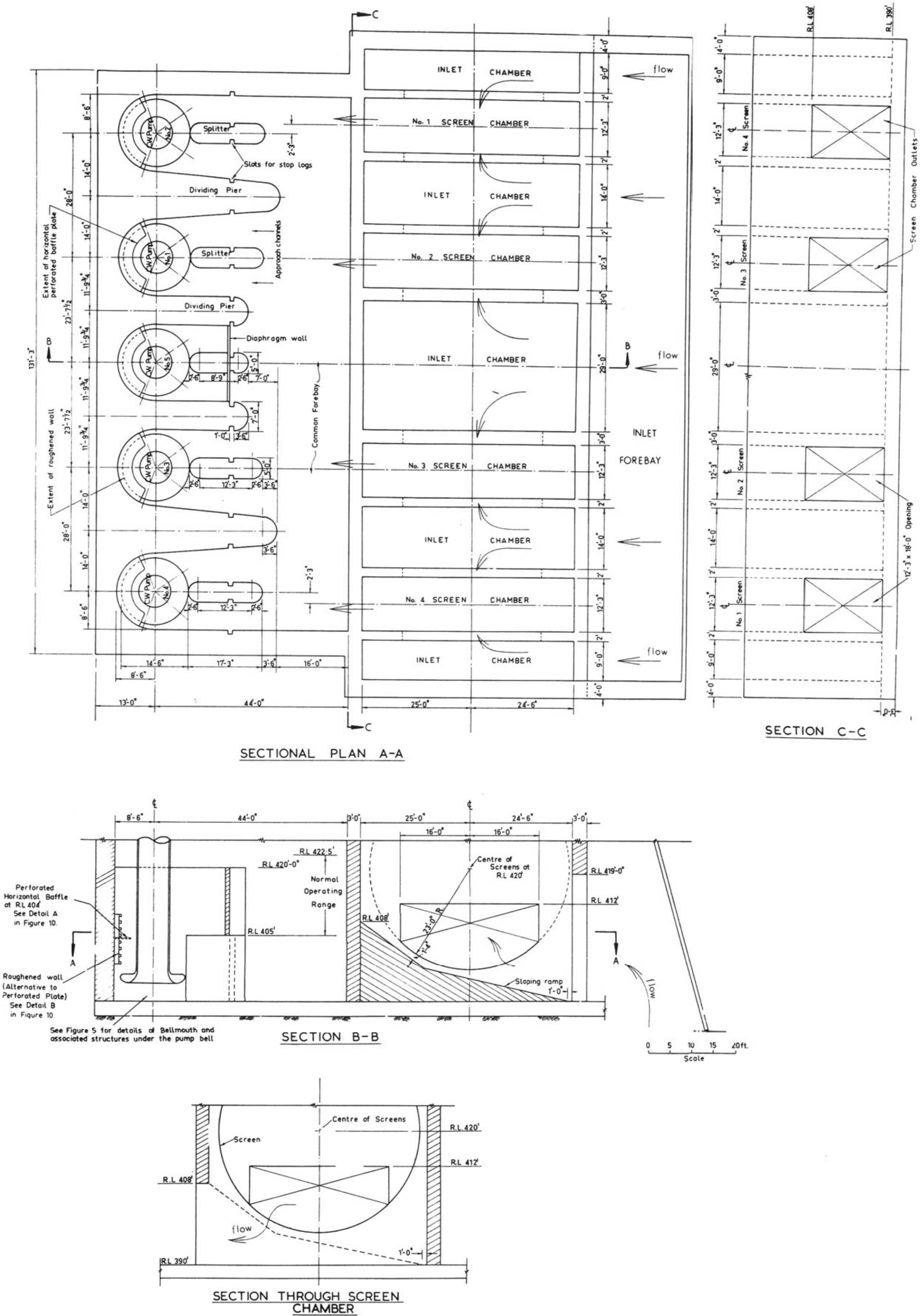


Figure 2: General layout of the main C.W. circulating pump intake.

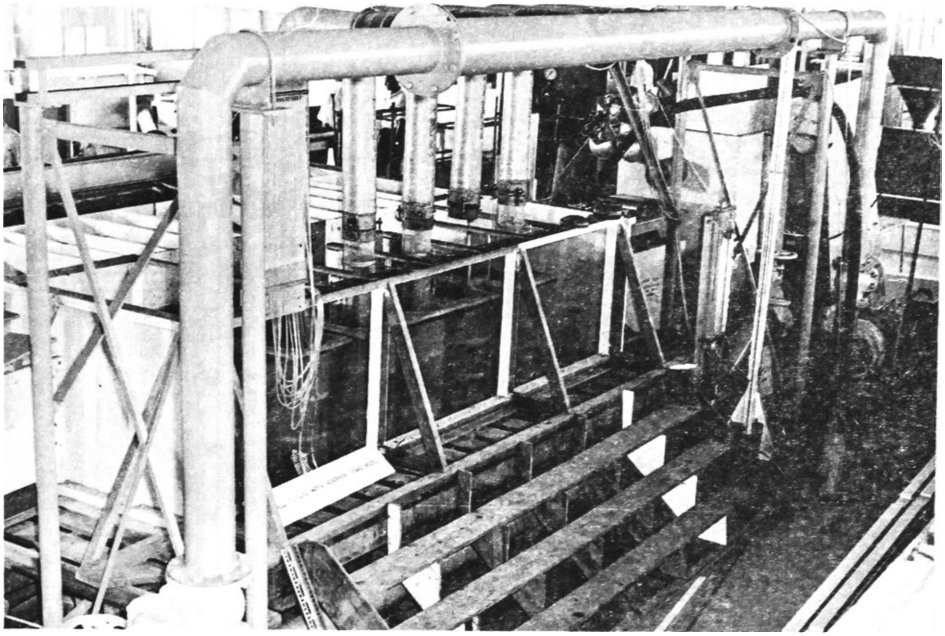


Figure 3a: Front view of model pump intake with "Perspex" wall to aid observations.

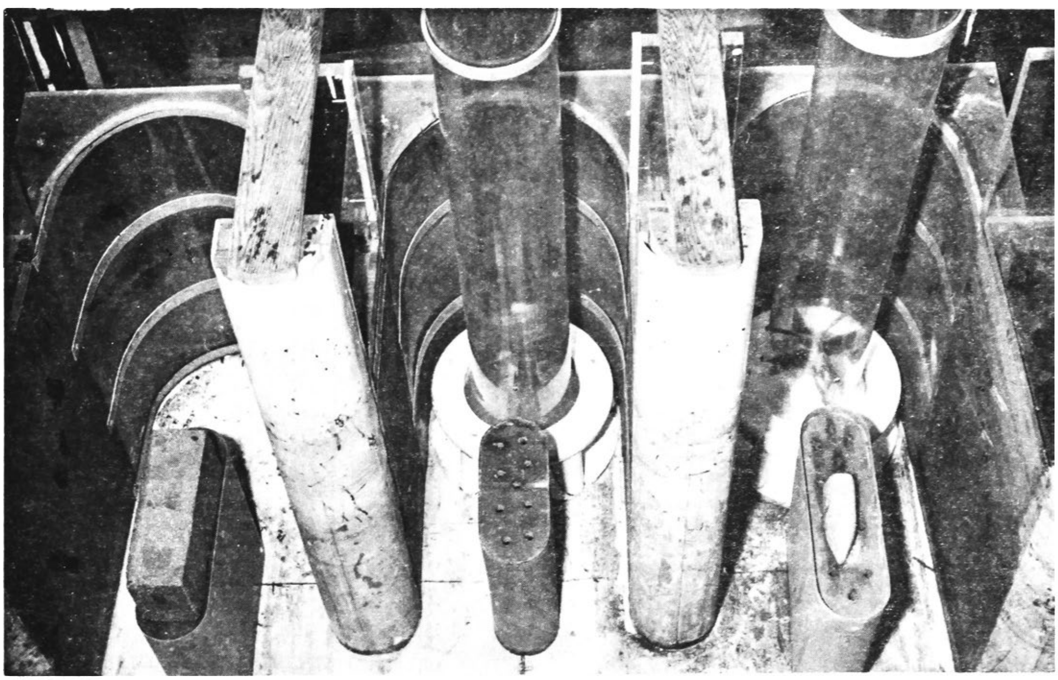


Figure 3b: Back view of the same model.

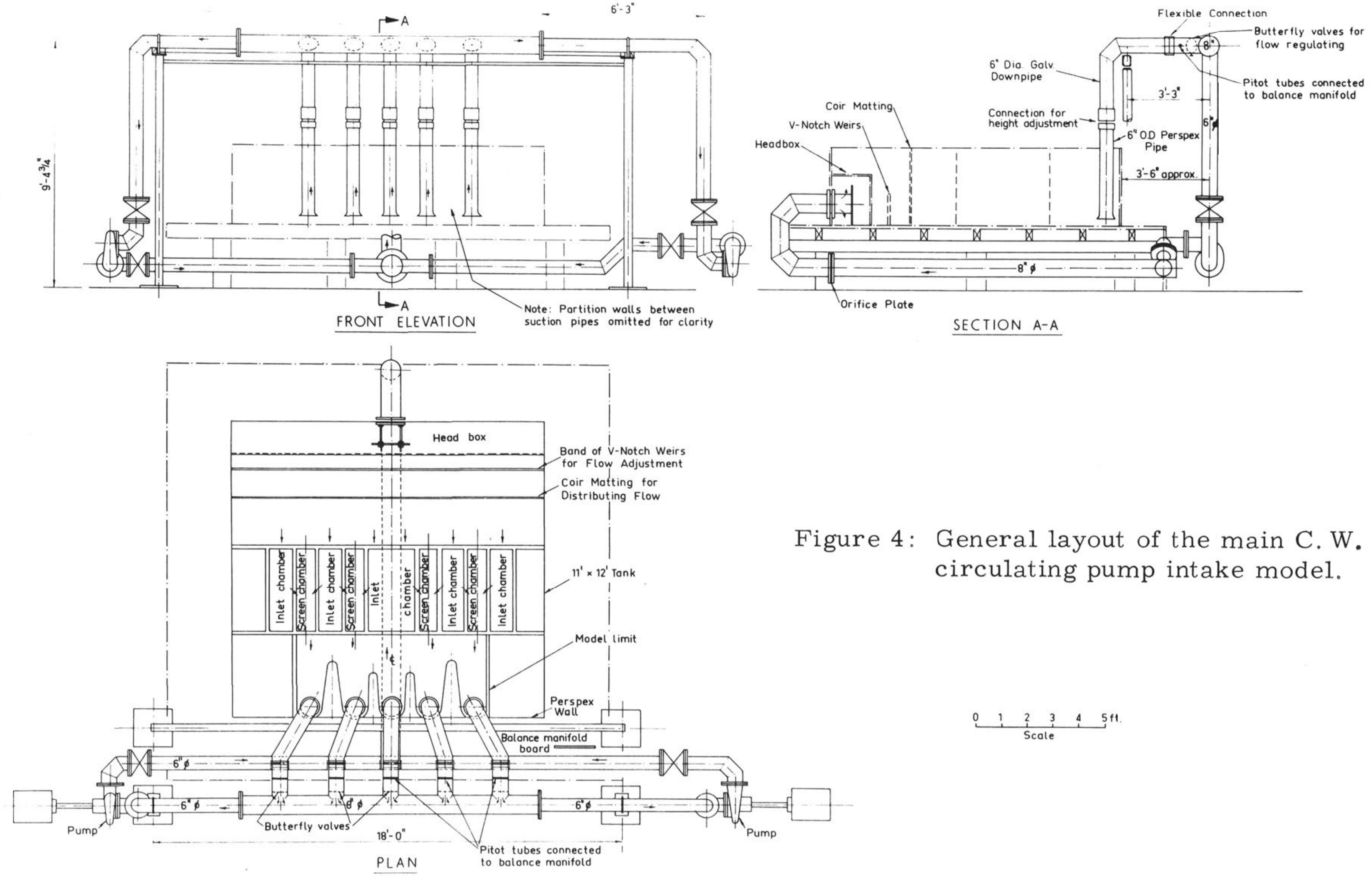


Figure 4: General layout of the main C. W. circulating pump intake model.

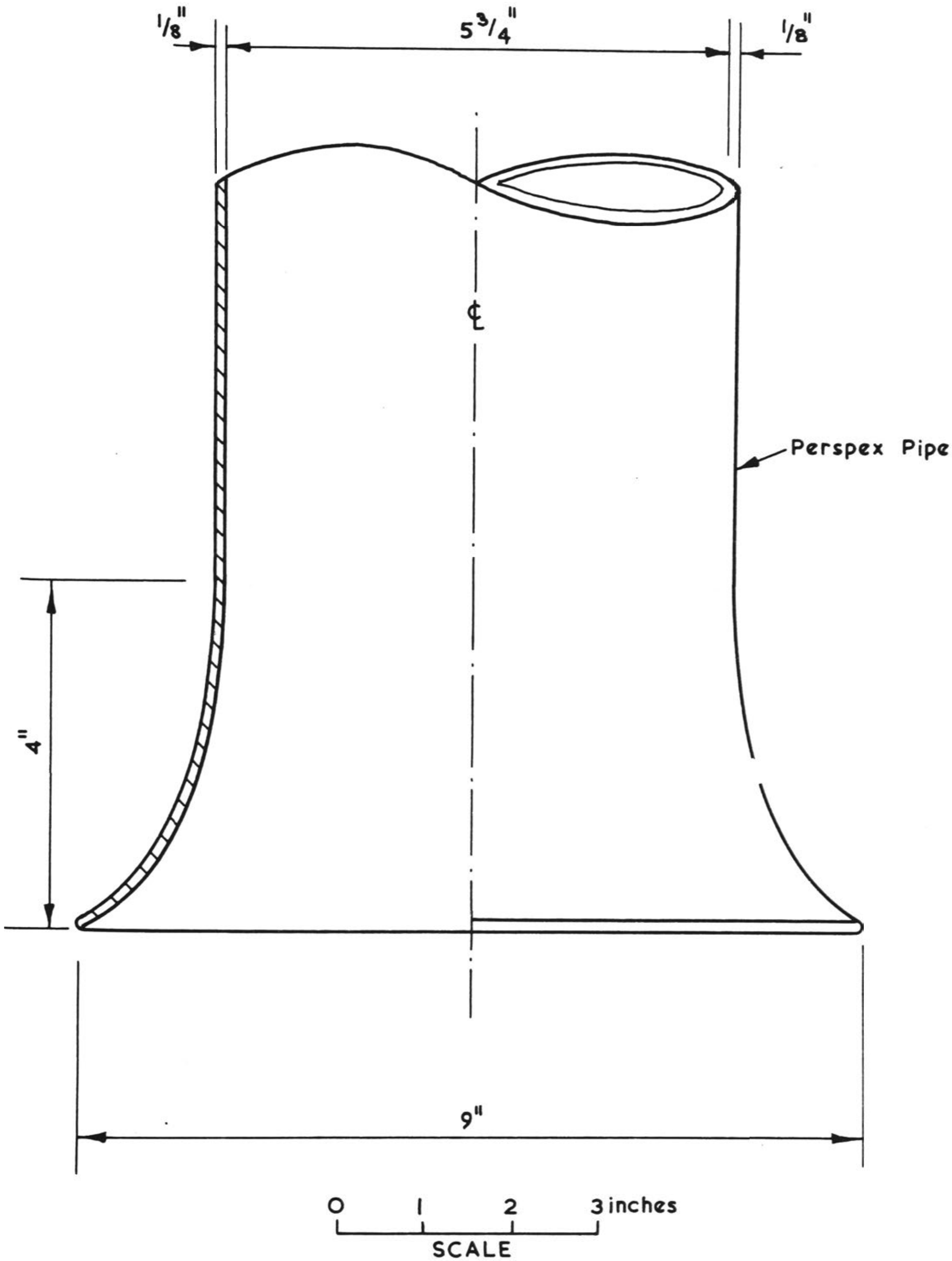


Figure 5: Simple model bellmouth.

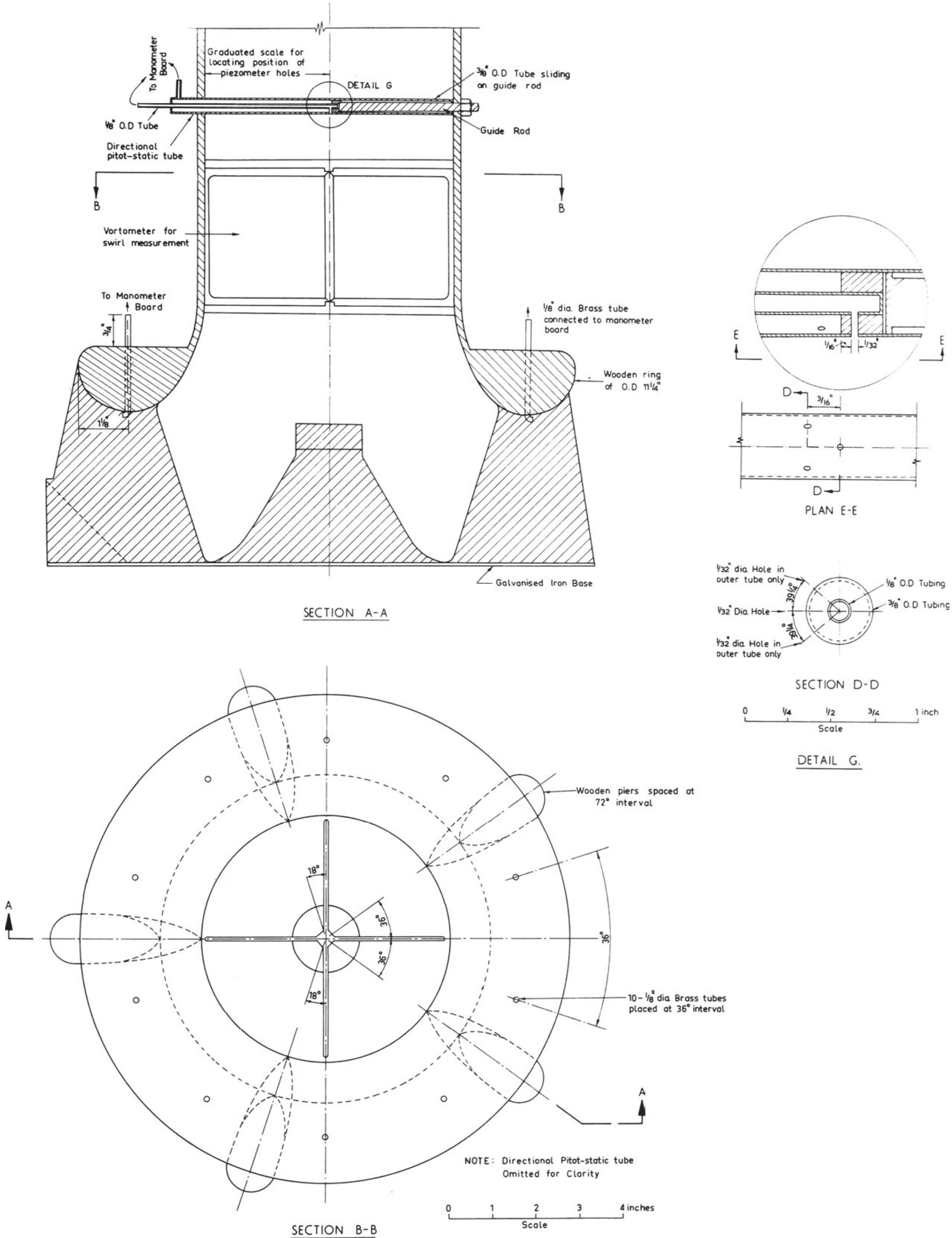


Figure 6: Instrumentation for the 1:16 scale model pump bellmouth.

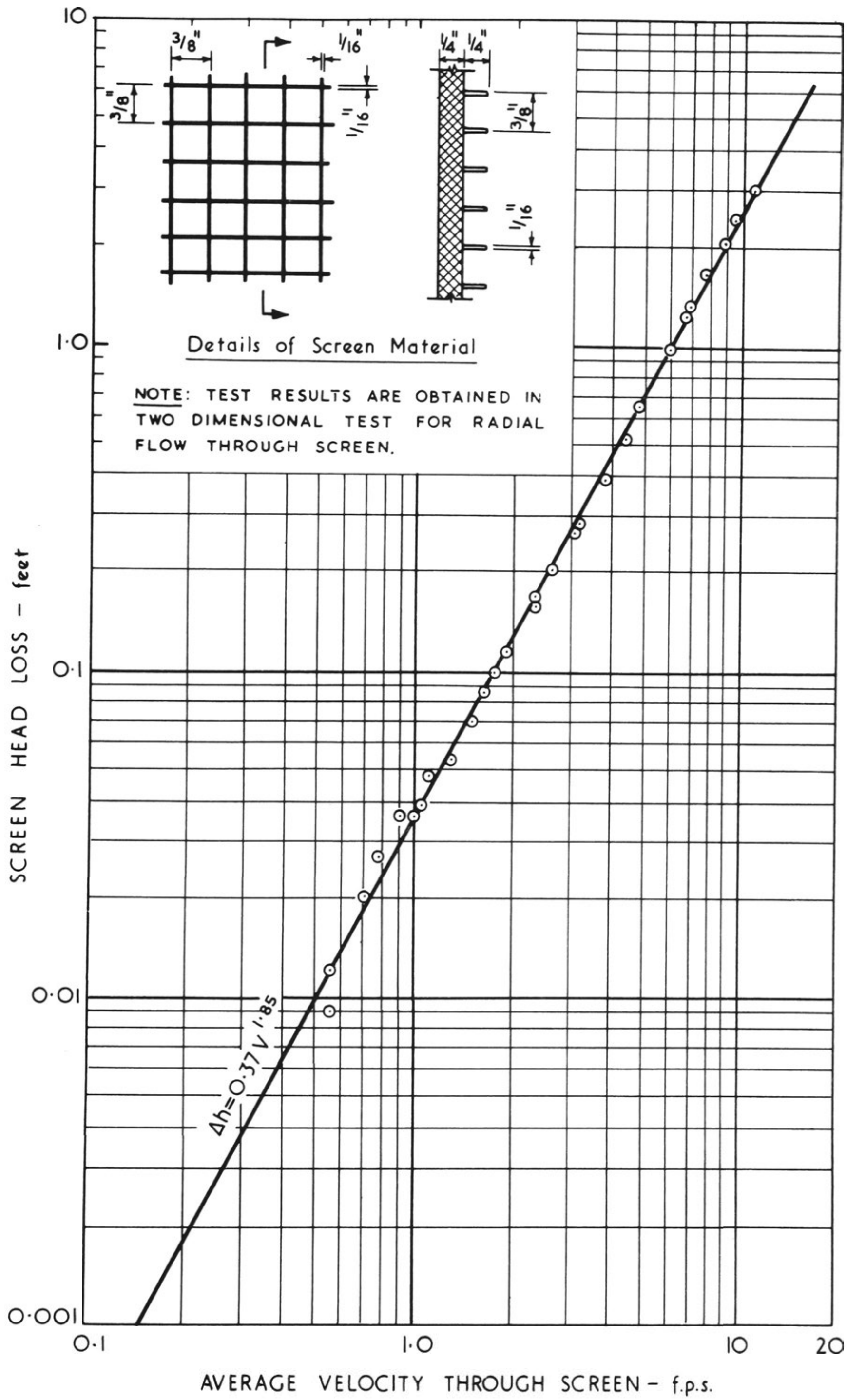


Figure 7: Headloss gradient of screen material for drum screen.

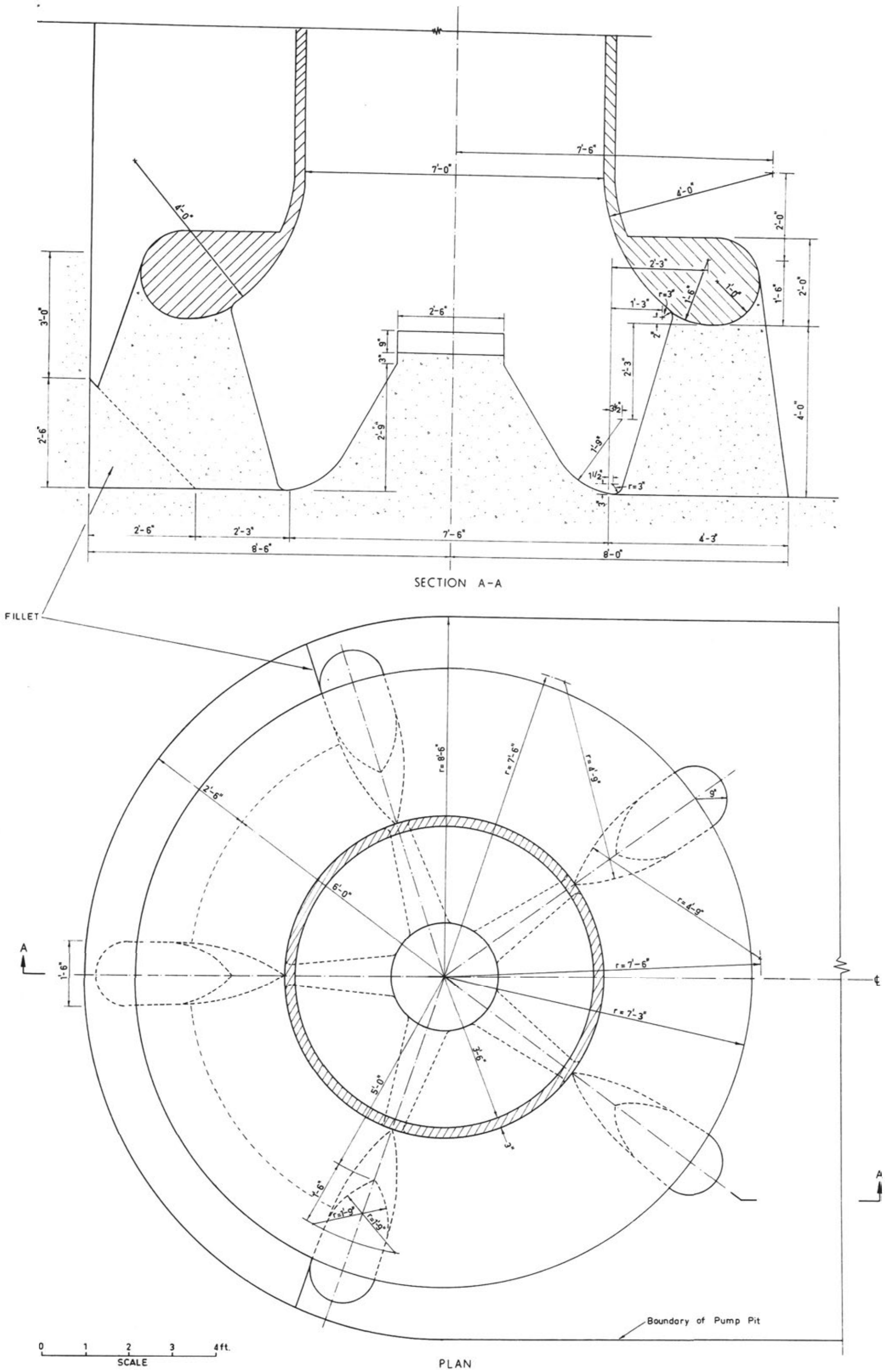


Figure 8: Details of pump bellmouth and its associated structure.

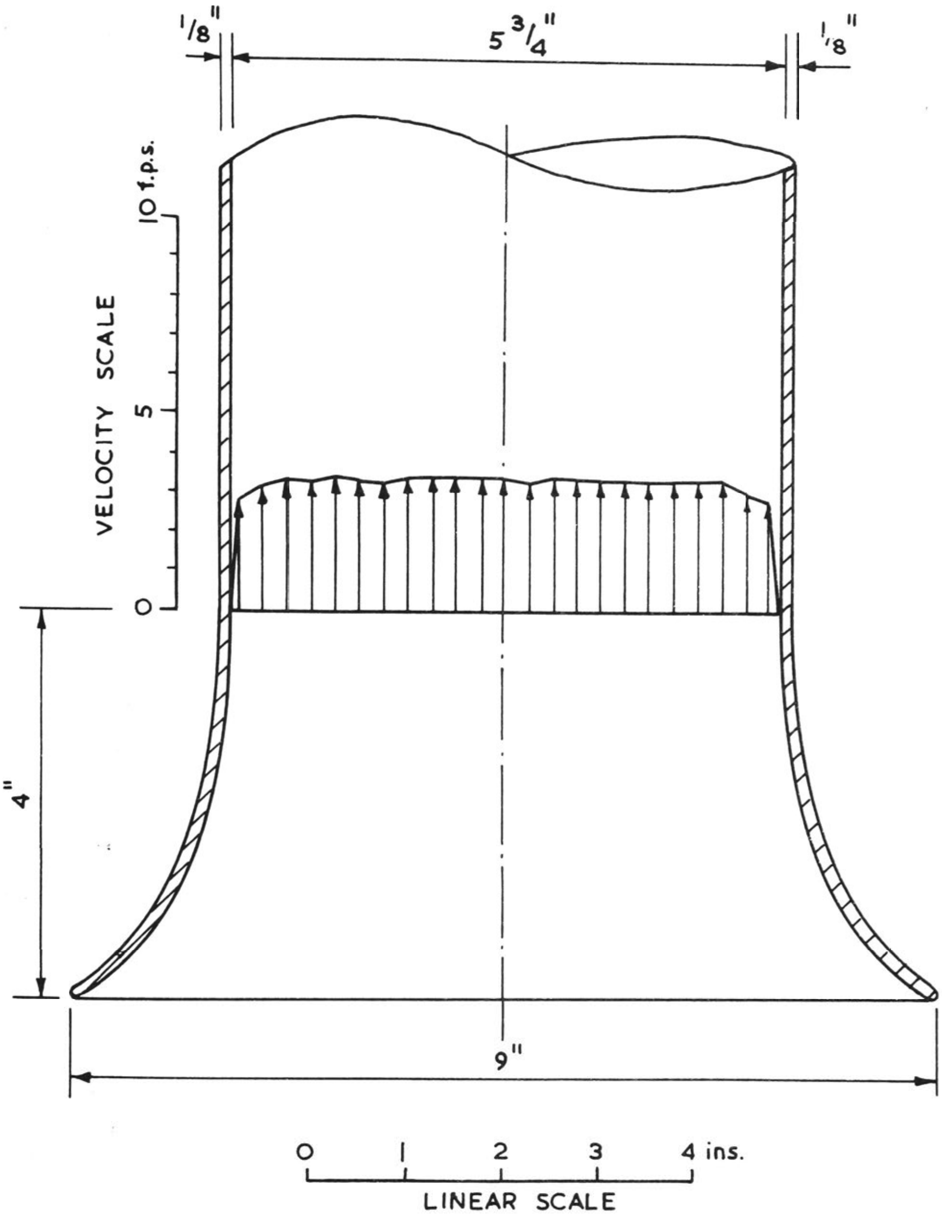
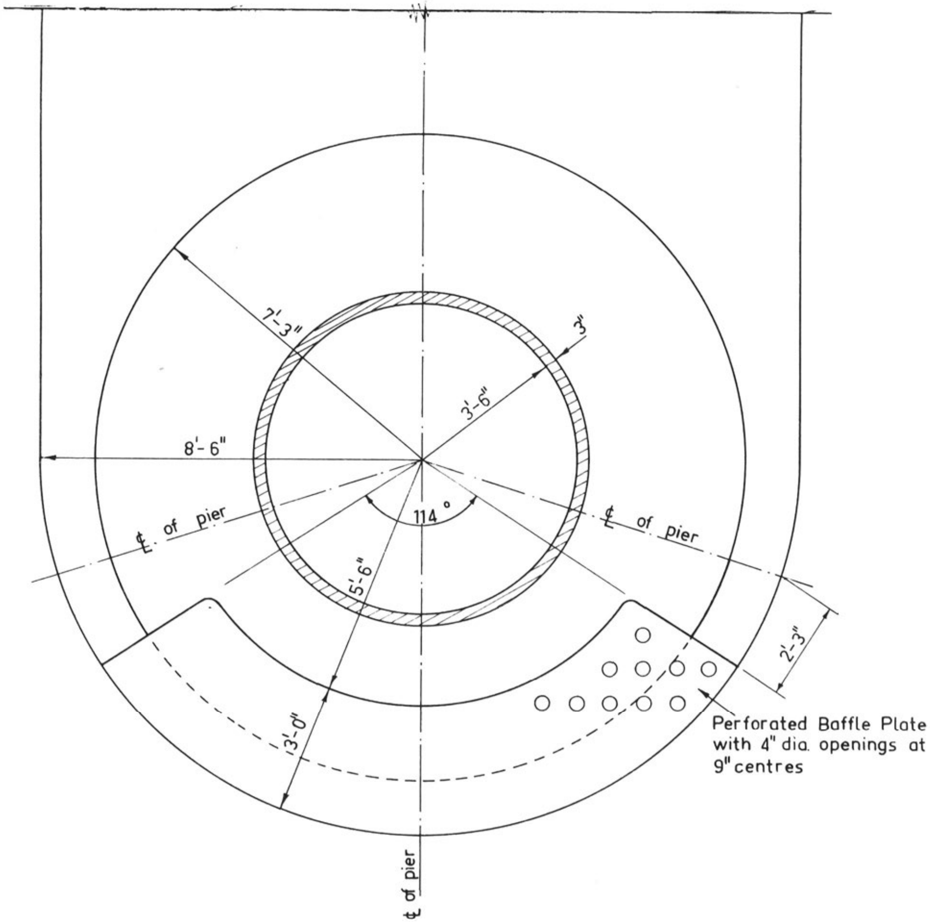
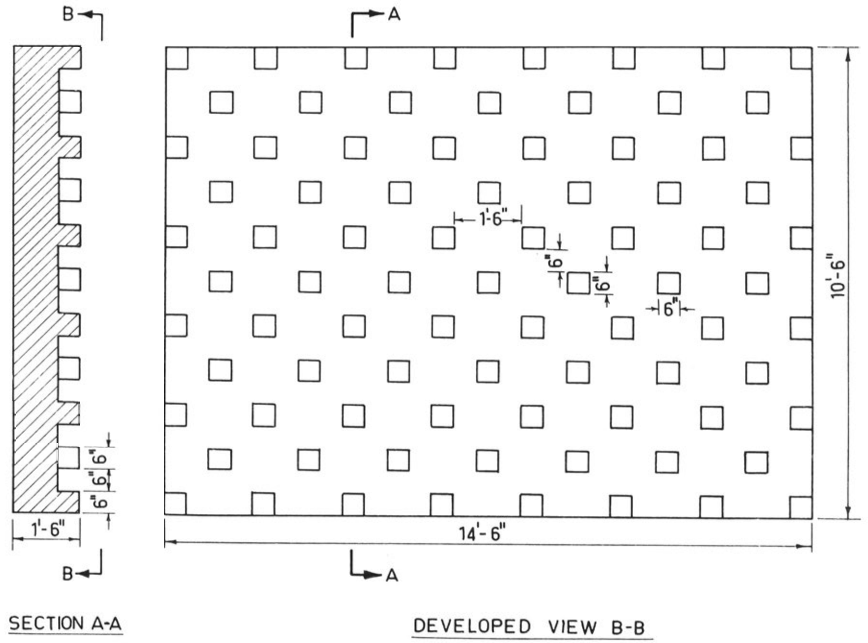


Figure 9: Typical velocity distribution as measured across the diameter of a model suction inlet.



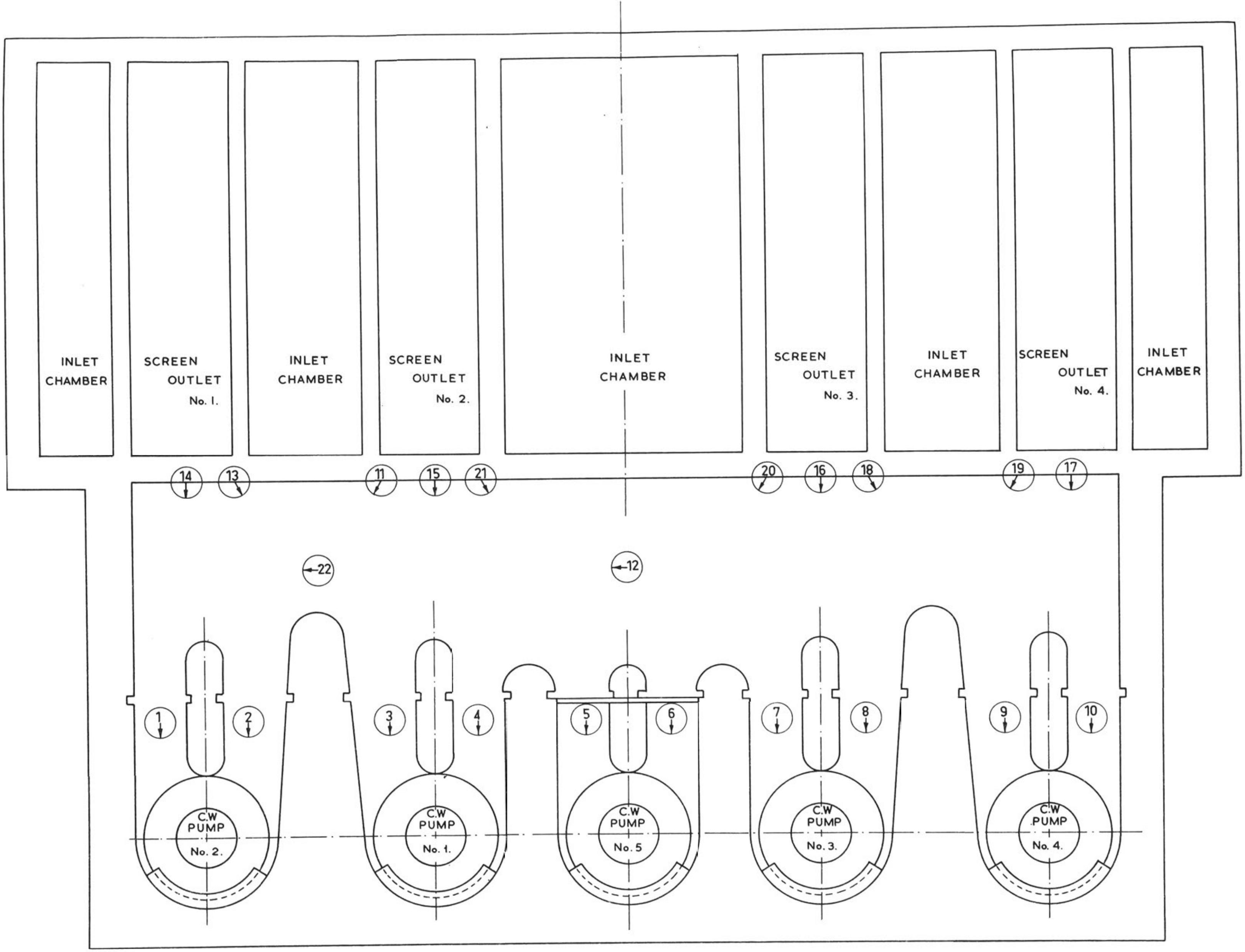
DETAIL A: PLAN OF PERFORATED BAFFLE PLATE

0 1 2 3 4ft.
Scale



DETAIL B: ROUGHENED WALL IN ELEVATION

Figure 10: Details of perforated baffle plate and roughened wall.



NOTE: Arrow inside the circle indicates direction of flow

Figure 11: Location of points for velocity measurement.

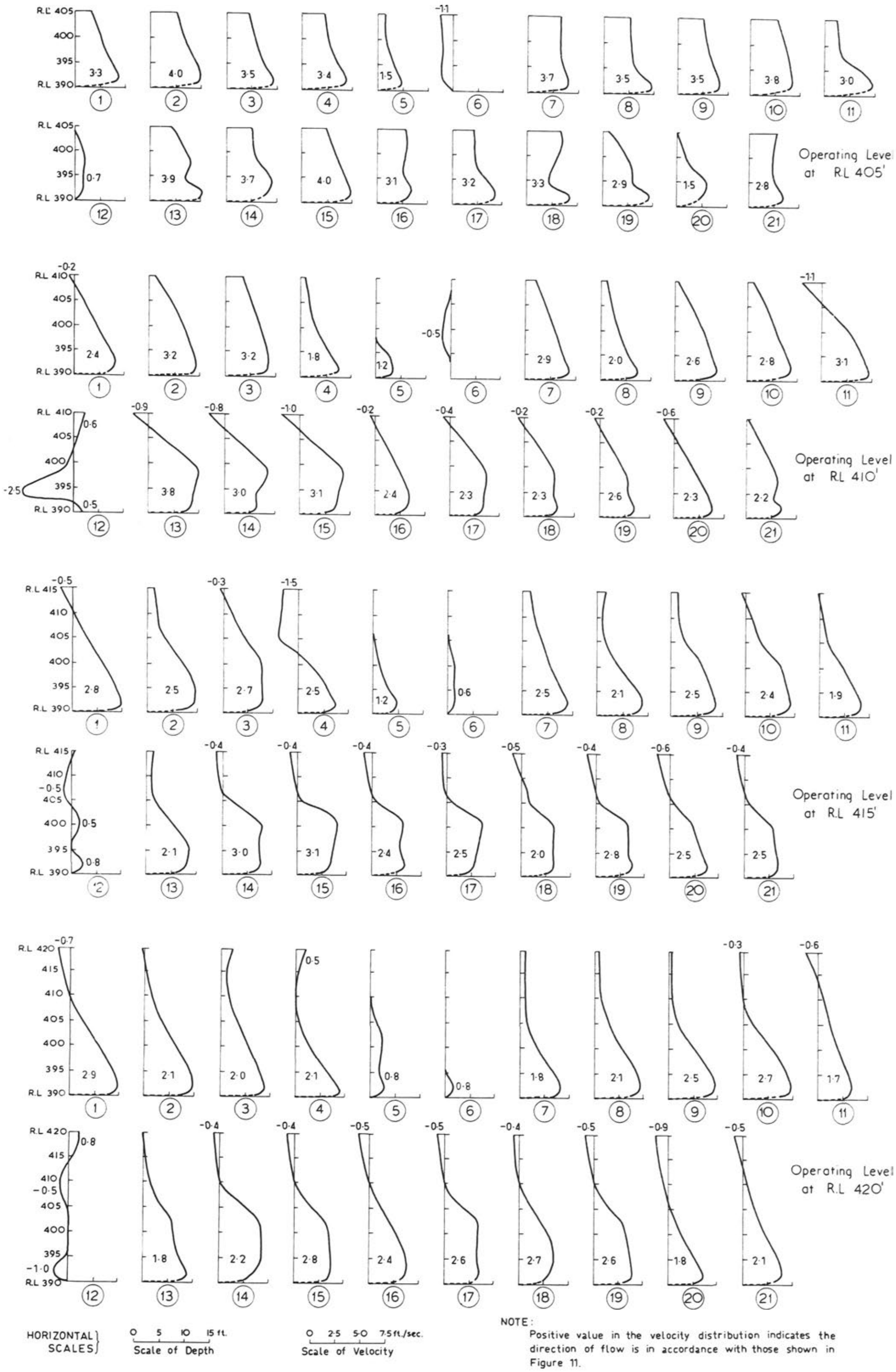


Figure 12: Velocity profiles for operating conditions: Pump 1, 2, 3, 4; Screens 1, 2, 3, 4 and Q = 2240 cfs.

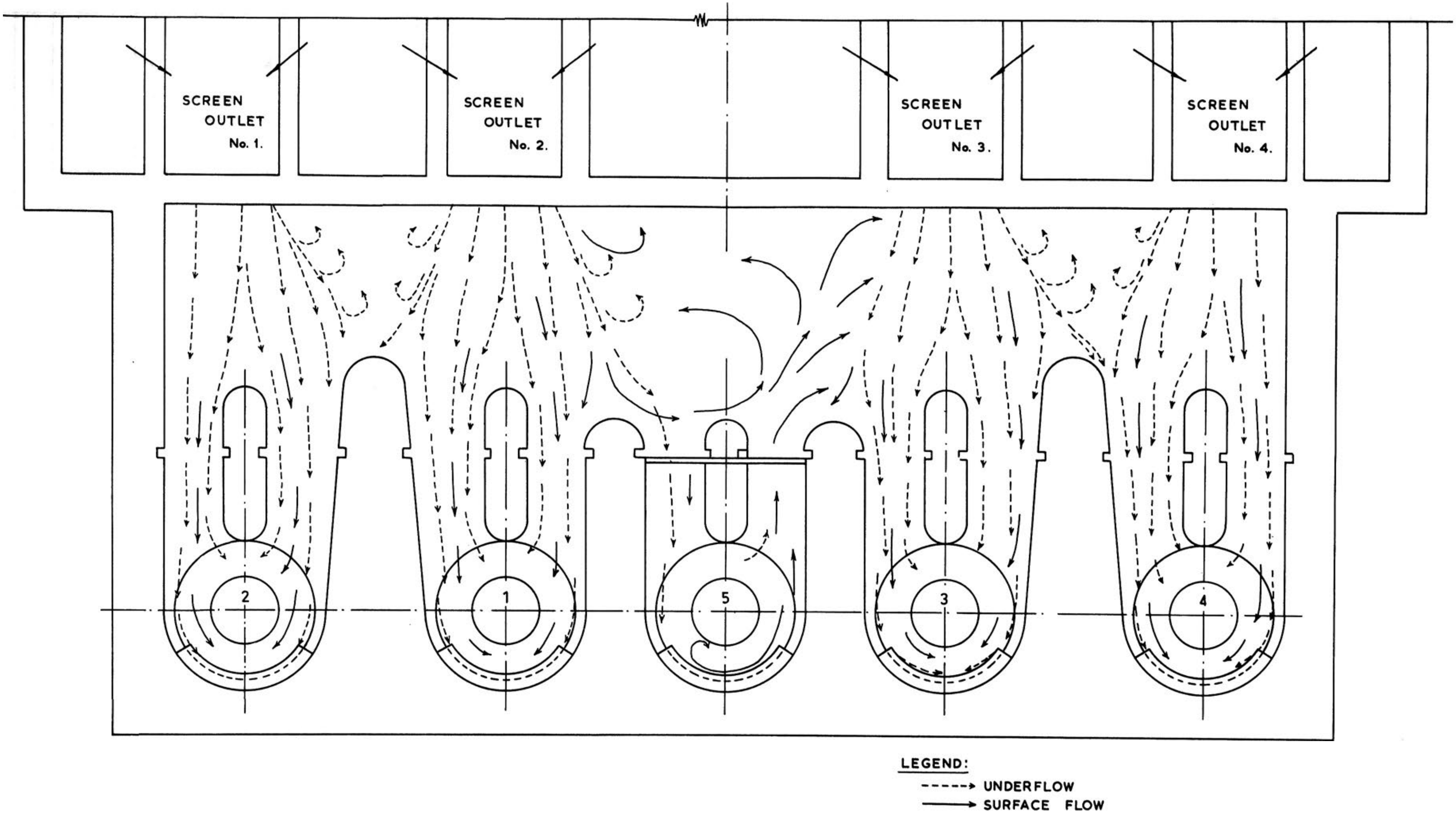


Figure 13: Flow patterns for operating conditions as given in Figure 12, at RL. 405'.

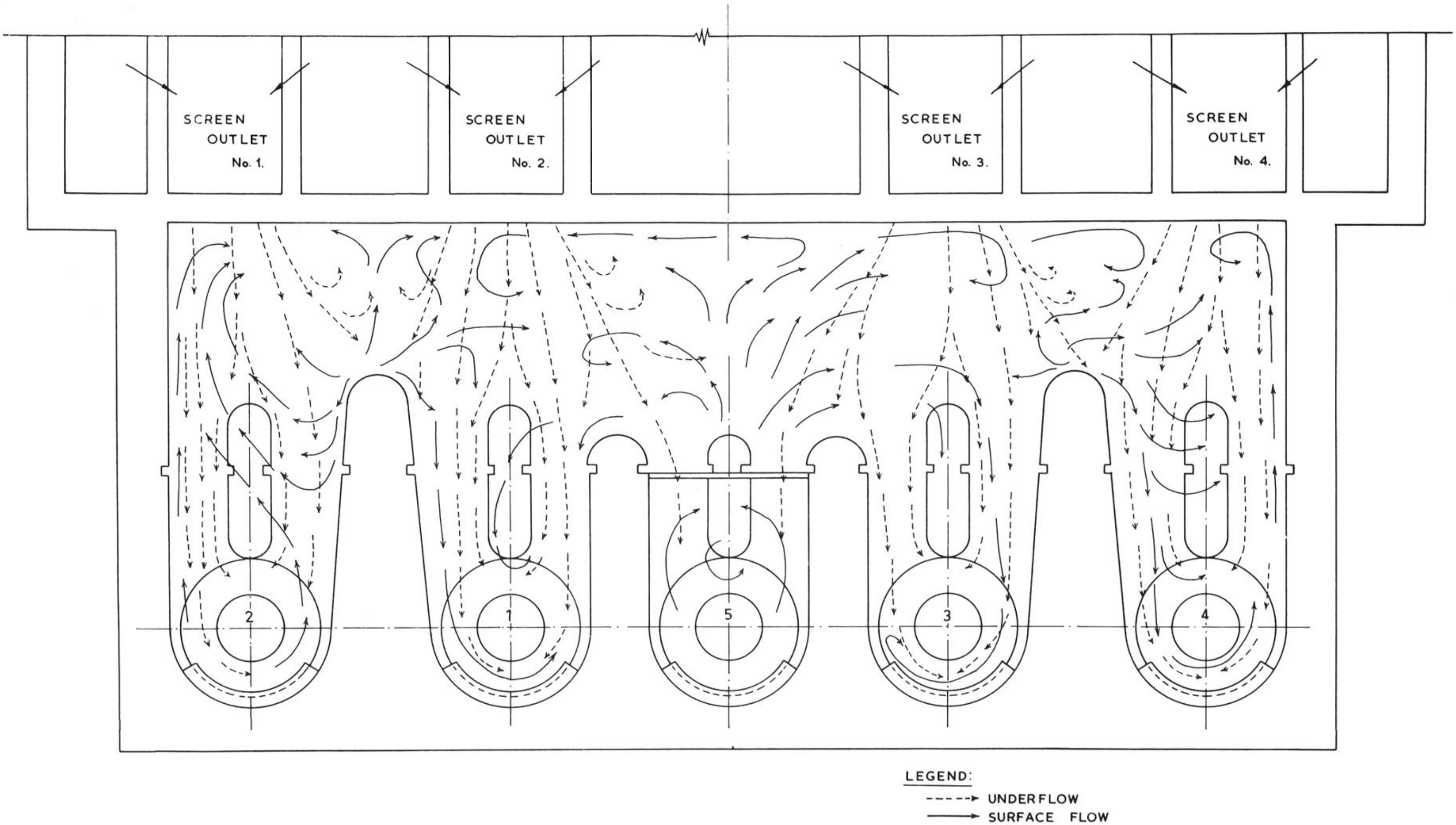


Figure 14: Flow patterns for operating conditions as given in Figure 12, at RL. 420'.

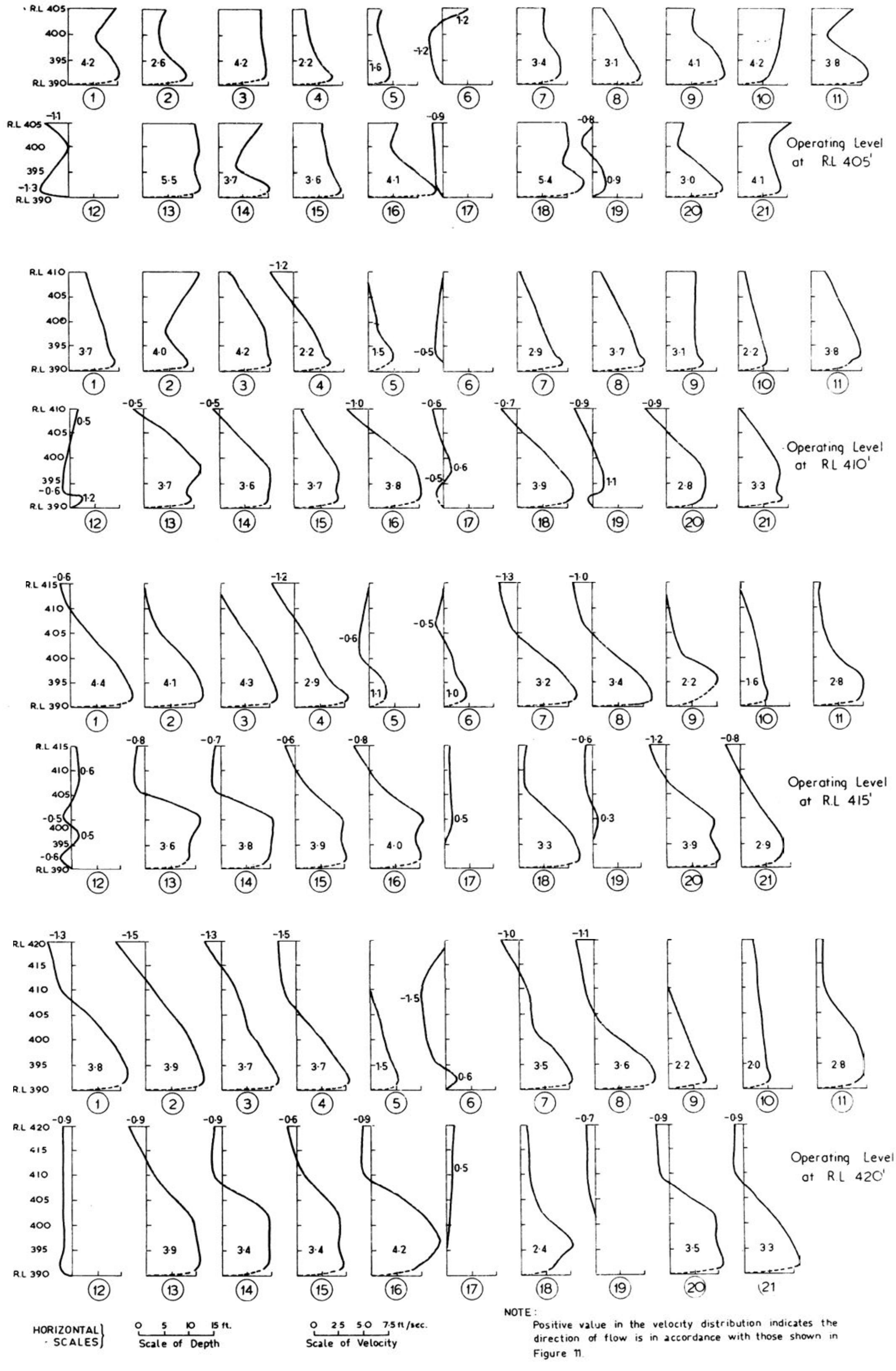


Figure 15: Velocity profiles for operating conditions:
Pumps 1, 2, 3, 4; Screens 1, 2, 3 and Q = 2240 c.f.s.

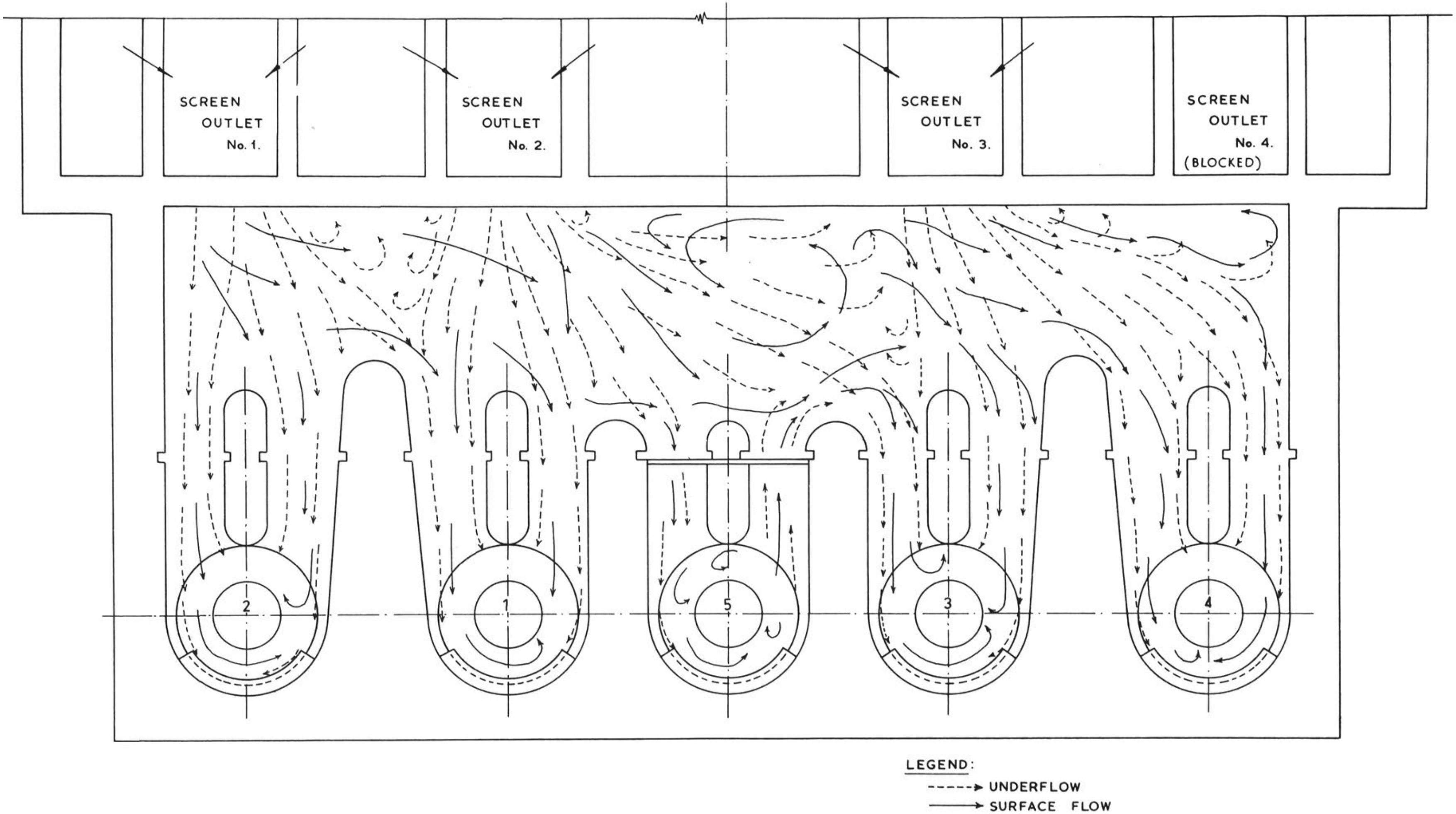


Figure 16: Flow patterns for operating conditions as given in Figure 15 at RL. 405'.

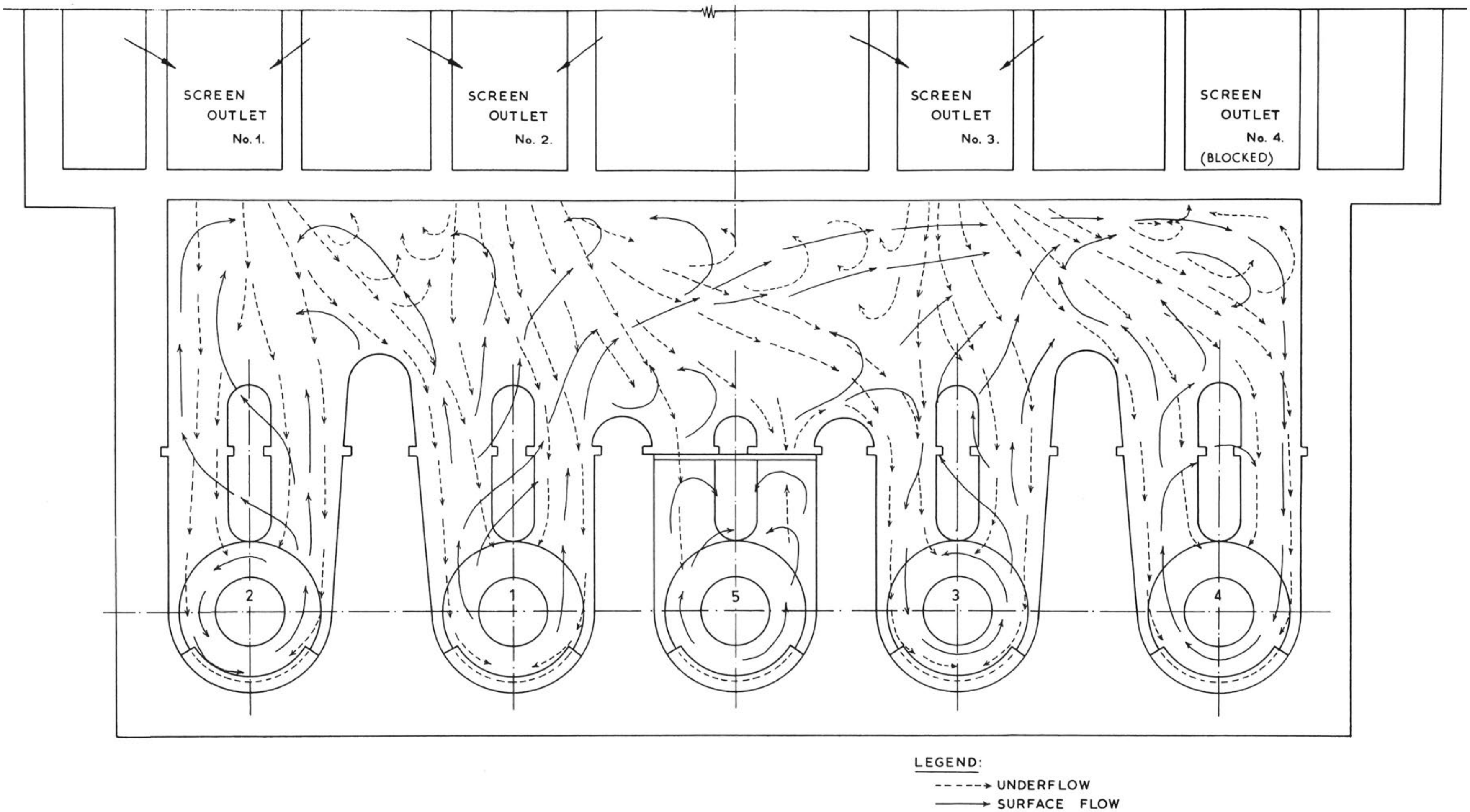


Figure 17: Flow patterns for operating conditions as given in Figure 15, at RL. 420'.

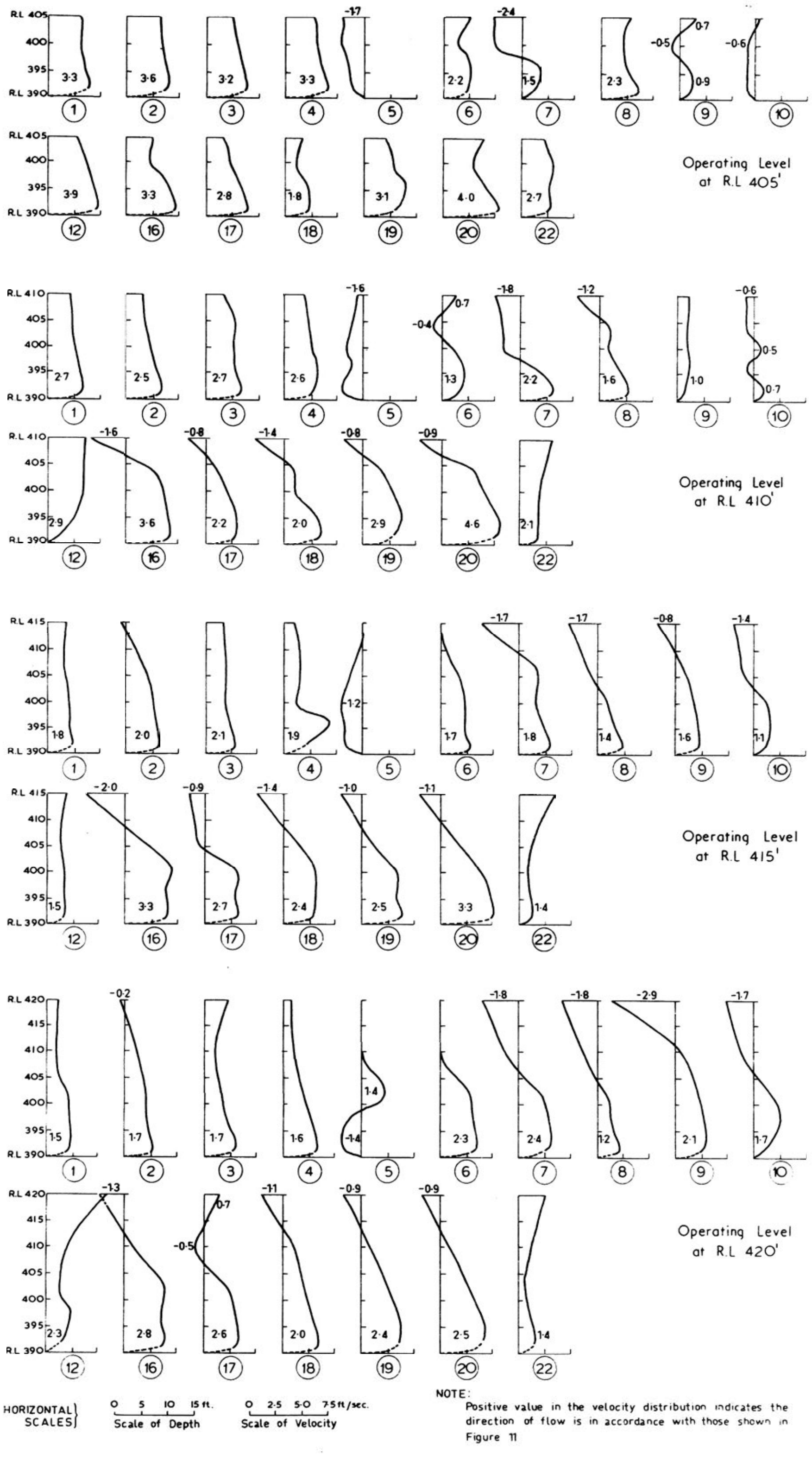


Figure 18: Velocity profiles for operating conditions. Pumps 1, 2; screens 3, 4 and Q = 1120 c.f.s.

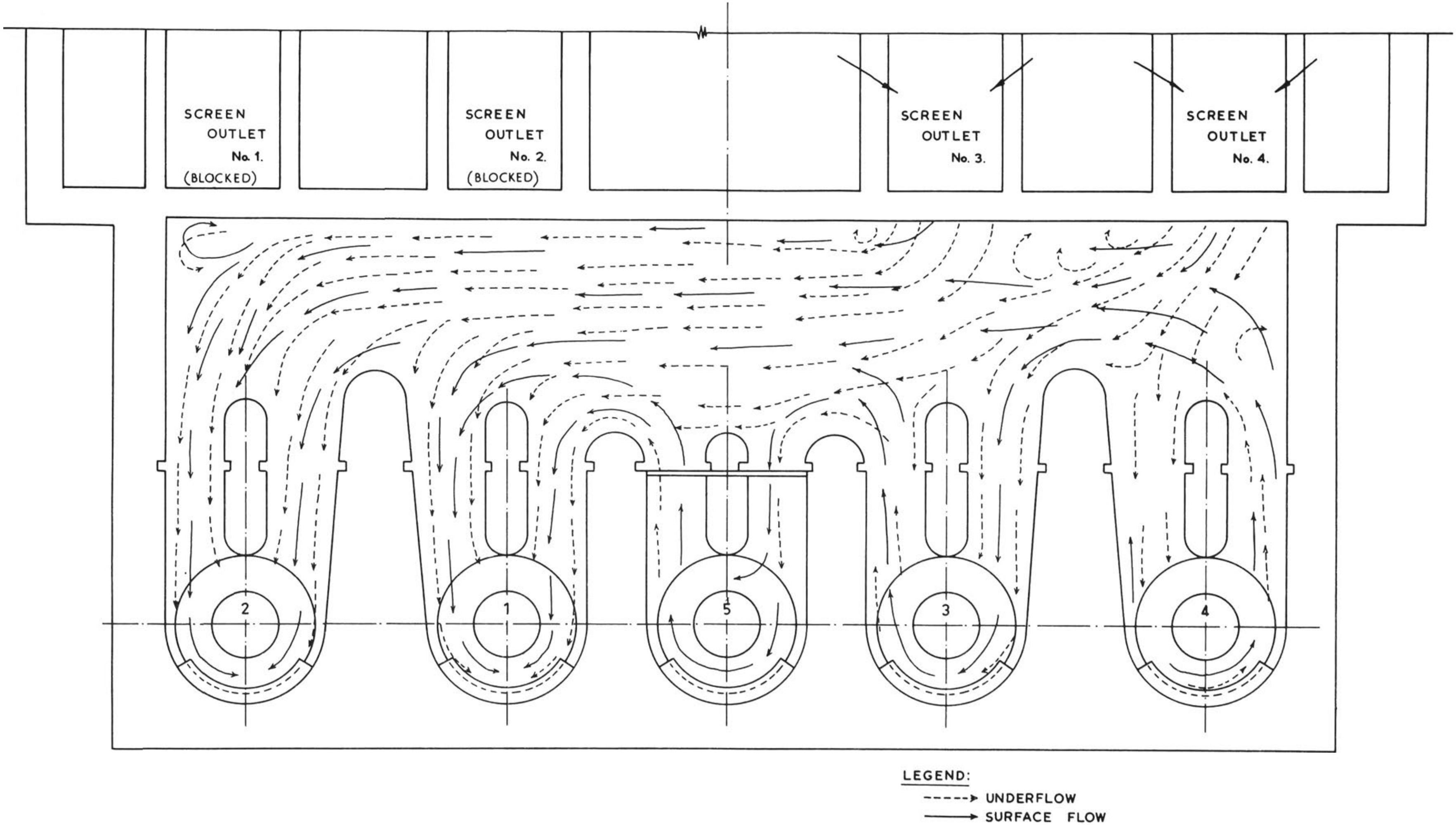


Figure 19: Flow patterns for operating conditions as given in Figure 18, at RL. 405'.

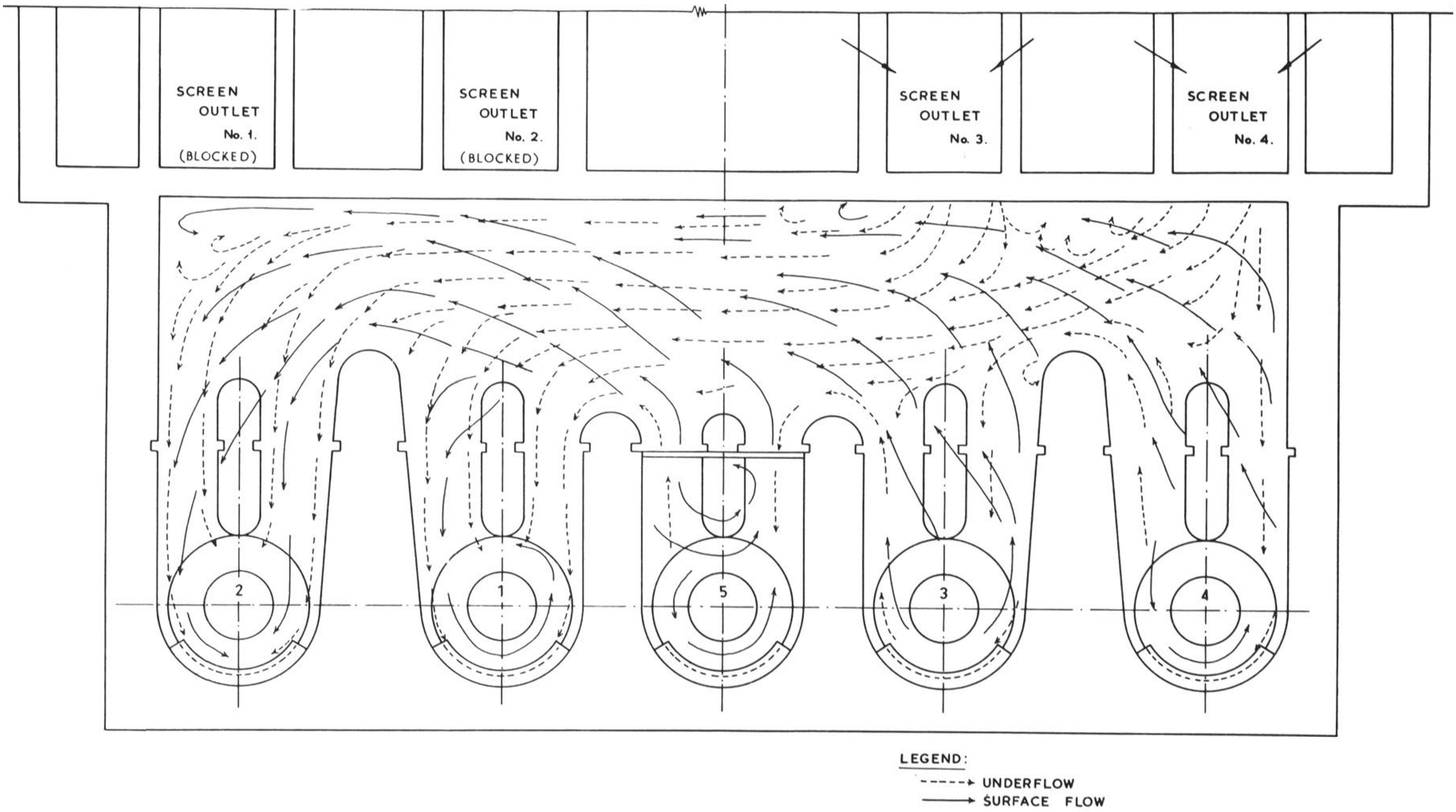


Figure 20: Flow patterns for operating conditions as given in Figure 18, at RL. 420'.